EXPERIMENTS WITH PLANTS

A First Schoolbook of Science

J. B. PHILIP

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A First School-book of Science

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INTRODUCTION

THE following chapters are intended not as a botanical lesson book, but as a general introduction to experimental science.

General Plan. Attention may be drawn to one or two features of the course.

1. The various subjects have been considered in their relation to the living plant as a centre round which they may be grouped in a natural way. Thus it has been possible to include such topics as the composition of the atmosphere, the importance of water, physical characteristics of the soil, the meaning of chemical union, changes of state and latent heat, the nourishment and reproduction of plants—without, it is hoped, sacrificing continuity of treatment.

2. The practical work involves (or may be accompanied by)—

(*a*) Employment of a variety of experimental methods, including the use of controls;
(*b*) Statements of results and conclusions;
(*c*) Arithmetical presentation of results;
(*d*) Discussion of questions suggested by the experiments;
(*e*) Tabulation of readings from temperature and other scales;
(*f*) Construction of graphs;

(*g*) Weighing and measuring, which are more satisfactorily taught as means to an end in the course of an experiment than as ends in themselves;

(*h*) Sustained observation, as in the case of the feeding of Drosera.

3. No attempt has been made to deal with the subject of any chapter in an exhaustive way. Many experiments coming within the scope of the book have been omitted, it being considered of greater educational value to deal with a few experiments fairly fully than to glance cursorily at many. This leaves room for the interpolation of additional experiments suggested by the pupils themselves.

Order of Study. As each chapter has been given a more or less independent setting, the order of the book may be departed from without inconvenience. Chapter I is, however, suitably taken first, and although it deals largely with germination, and is therefore appropriate to spring, it may be taken at any season, as the seeds required for the experiments will sprout indoors even in cold weather. Several other chapters, such as II, III, VI, may also be regarded as non-seasonal. Chapter IV, on the other hand, should be taken in the sunniest month of summer. Experiments requiring leafy shoots can only be done when suitable material is available, but fresh twigs or whole plants that will illustrate transpiration effects can be had well on into autumn. With reproduction there is still greater scope, for flowers can be got all the year round. Water culture experiments should be set agoing early—say in March or April—to allow of the results being sufficiently developed before the long vacation. Root-pressure experiments are most successful in spring.

Method. The various chapters are not intended to be learned as set lessons. Pupils should be plunged *in medias res* at once. Before a chapter is read through the experiments it describes should be set up with no more than necessary reference to the text. When all have been disposed of, the whole of the chapter may be taken as revision.

Laboratory work alone is not sufficient, and if class lessons alternate with it there is opportunity for discussing results, and for answering either orally or in writing the questions put down after most of the experiments and also in the Appendix. Of the experiments a large number should certainly be done by each individual pupil. Among these are the preparation of oxygen and carbon dioxide, testing the leaf for starch, and many more.

Others again might be shown to the class, but the extent to which this should be done is a matter for each individual teacher to settle, and will depend partly on the size of the class and partly on other considerations, as for example the available supply of mercury (Experiment 22). In any case this experiment goes well as a demonstration lesson. The experiment with the candle burning in a closed space is well suited for similar treatment, as it raises a number of questions which may be profitably discussed and disposed of, experimentally or otherwise, just as they occur.

Experiments may also occasionally be dealt with by the class collectively, some watching the results and giving readings, or making weighings, as the case may be, while the rest tabulate the figures or express them in graphic form. This will keep a class quite busy, especially in such experiments as No. 31, where the rise of water is so rapid that an observation should be made every half-minute.

References to the Appendix are given throughout the book. The questions in Appendix A might be taken as a revisal exercise on the first seven chapters.

Not the least important part of the course will be the pupils' records of their own observations and conclusions, together with descriptions and drawings All these should be made in a special note-book large enough to contain a session's work and provided with alternating ruled and unruled pages, and at least a dozen pages of squared paper at the end. If loose-leaf note-books are used it will be possible to insert ruled, plain, or squared sheets as required.

Comparatively brief entries of laboratory work should be the rule, but for practice in description and reasoning selected experiments might be dealt with at some length. If along with these accounts, shorter or longer, there are tables of readings, graphs, arithmetical problems, answers to sets of questions, and of course frequent sketches, each pupil's book should at the end of the session be found to present a varied and instructive review of the work overtaken.

The illustrations are partly from original photographs and partly from line and half-tone drawings. For the latter the author is indebted to Mr. C. R. Leslie Millar, Art Master, Grammar School, Aberdeen.

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CHAPTER I

THE PLANT AND THE ENVIRONMENT

MUCH of any one's knowledge, general or scientific, is really only information. It has been gained by reading or hearing the facts and not by actual examination of them. The facts, of course, may not always be at hand when we wish to examine them. In many cases, however, it is possible to make them occur, and our attempt to do so at a time convenient to ourselves is called an experiment. Take a simple example of what is meant. We have heard, perhaps, that water expands before it freezes, but we wish to prove this for ourselves. We fill a strong bottle full of water and leave it outside during a frosty night. In the morning we find the bottle broken. We do not need to be told this. We see it with our own eyes. This, however, is not the whole matter, as will presently be seen. But first let us go back to the beginning, which was our desire to find something out. This is the *purpose* of the experiment. Then there comes the suggestion of the general way in which this may be accomplished, in other words—the *plan* of the experiment. Then there is the actual *setting-up*, followed either immediately or after the lapse of some time by the *result*. If this fact leads us on to another which explains what has occurred, we reach the *conclusion* or *inference*. This is the most important part of the whole process. The most natural conclusion in the above experiment would be that pressure has been developed in the bottle and that this must have been due to the expansion of the water, as there was nothing else inside. The stages in an experiment, then, are the *purpose*, the *plan*, the actual *setting-up*, the *result*, the *conclusion*.

1. Suggest a modification or extension of the experiment to show that the breaking of the bottle was not due to increased external pressure caused by the cooling of the air.
2. Another possible conclusion would be that the pressure was created by the bottle contracting. Give any facts that might seem to support this view.
3. Give examples of heat causing breakage.

In some experiments the results are progressive and require continued observation. In this case notes should be made at intervals during the course of the experiment.

Let us now proceed to one or two experiments which we choose to begin with because they are easily set up, and also serve as an introduction to the subject dealt with in the following chapters. They will show that a plant is acted on in various ways and by various forces. Let us start with three sources of energy familiar to every one—light, heat, and gravity. The purpose of our experiments is to find out if these influences have any effect on growing plants. Light and heat both have their origin in the sun and from a distance of millions of miles act at the surface of the earth, enabling people to see their surroundings and to escape being killed by the cold. The third force has its origin in the earth itself. It is the force that makes the apple (as well as other things) fall to the ground instead of flying off into space.

Light. Plants have no eyes. Do they need light?

In daily experience, the best way to discover how useful anything is, is to try and do without it. Apply the same method in this case to plants. Grow them in absolute darkness.

Experiment No. 1.

Apparatus and Material.

White mustard seed.
Two flower-pots.
Potting soil.

Mustard seed is chosen because it sprouts (or germinates) quickly. Sow it in the usual way and put one of the pots near a window and the other in a dark press or box. Water the pots when necessary, which will not be often if a bell-jar or ordinary glass shade is put over each. In about a week the results will show. Comparing the two sets, we easily see that those grown in the dark are not of the usual green colour, but look pale and weak. The conclusion is that light has a very great influence on the plant.

1. In what respects besides loss of colour have the leaves been affected?
2. How do the stems differ in length, strength, and direction of growth?
3. On what parts do you find hairs?
4. Does darkness make any difference to them?
5. How would you find out if the defects due to darkness can be removed?

Perhaps it might be suggested that want of light does not affect older plants in the same way as it does those just emerging from the seed. This can easily be ascertained.

EXPERIMENT NO. 2.

Apparatus and Material.

Turnip with root and leaves.
Flower-pot.
Potting soil.
Tall dark box.

After the turnip has been planted in the pot, water the soil and put the whole thing in the dark box, which should be tall enough to permit of the stem shooting up for two or three feet. If a box is not available place the pot in a cellar or press. After the turnip has been growing in the dark for a week or two, it will be easy to see whether it has been affected by the absence of light in the same way as the mustard seedlings. This experiment is best done early in the year.

1. Account for the turnip growing as well as it does under conditions that are obviously unhealthy.

2. Point out similarities between the turnip and the mustard seedlings raised in the dark.

3. What conclusion as to the special effect of light might be founded on the fact that certain parts of plants grown in the dark are small?

It may be noted that the experiments in this chapter all require some time to develop. One should therefore not wait for the results of No. 1 before setting up No. 2. Set them all agoing, one after the other, and deal with the results as they are ready.

Heat. Heat is a form of energy derived from the sun, and its value is universally recognized by all interested in the production of crops. Nature frequently makes an experiment for us when a very cold summer demonstrates the bad effects of the absence of heat. Let us repeat this experiment on a smaller scale, substituting a box for the countryside, a couple of weeks for the whole summer, and mustard for the usual field crops.

EXPERIMENT NO. 3.

Apparatus and Material.

An ounce of mustard seed.
Two gardener's boxes.
Potting soil.
Two thermometers.

Sow as usual and place the boxes under widely different temperature conditions. Put one in a hothouse and the other out-of-doors or close to the window of a room or out-house in which there is no artificial heating. If the experiment is carried out in winter time, there will be no difficulty in keeping one box 20 or 30 degrees Centigrade hotter than the other.

1. Record the temperatures[1] several times a day and tabulate them as shown below.

2. Give details showing the superiority of the seedlings raised in the hothouse.

The following table includes some of the readings taken while mustard was being grown under three different conditions of temperature :

Date.	*Hothouse—warmer end.*			*Hothouse—cooler end.*			*Tool-shed.*		
	M.	N.	E.	M.	N.	E.	M.	N.	E.
Feb.									
15	11·0°	18·5°	17·5°	8·0°	19·5°	9·5°	0°	3·5°	3·0°
16	12·5	16·5	17·0	10·0	14·0	14·5	1·5	4·0	3·5
19	13·5	14·5	15·5	11·0	10·5	12·0	3·0	4·5	3·5
20	12·5	10·5	14·0	10·0	7·5	8·5	3·0	4·0	4·5
23	11·0	19·0	16·0	9·0	16·0	13·0	3·5	4·5	4·0

M. = between 7 and 8 a.m ; N. = noon ; E. = between 5 and 6 p.m.

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[1] See Appendix B : Thermometer.

1. The hothouse faces west and is divided into two, the north end receiving most artificial heat. Find the two days on which there was a strong sun.

2. Give possible reasons for the fall between morning and noon in the hothouse on the 20th.

3. Can you draw any conclusion with regard to the exposure of the window of the tool-shed?

4. Find from above table average reading for each column.

5. Assuming that the readings given are representative of the whole period, find the average temperature during the day, 1st in the warm end of the hothouse, 2nd in the cool end, 3rd in the tool-shed.

Gravity. We come now to the force of gravity. Owing to its constancy, it arrests our attention less than light and heat, which, by their coming and going, cannot escape the notice of any one. The method here is rather different. Instead of removing the plant from the influence of the force in question, we change its relation to it in order to see if the plant can adapt itself to this.

EXPERIMENT NO. 4.

Apparatus and Material.

Broad beans that have been growing in pots till their roots are two or three inches long.
One or two wide-mouthed bottles.
Splinters of wood with sharp ends.
Corks to fit the bottles.
Blotting-paper.

Line the bottles with blotting-paper and then pour in a little water which will be soaked up by the blotting-paper and very soon make the air inside the bottle quite damp. By aid of a splinter, which has to be fixed with one end in the cork and the other in the bean, the latter is to be supported inside the bottle with its root pointing straight up. It is better to set up two or three of this experiment in case of failure. Put the bottles inside

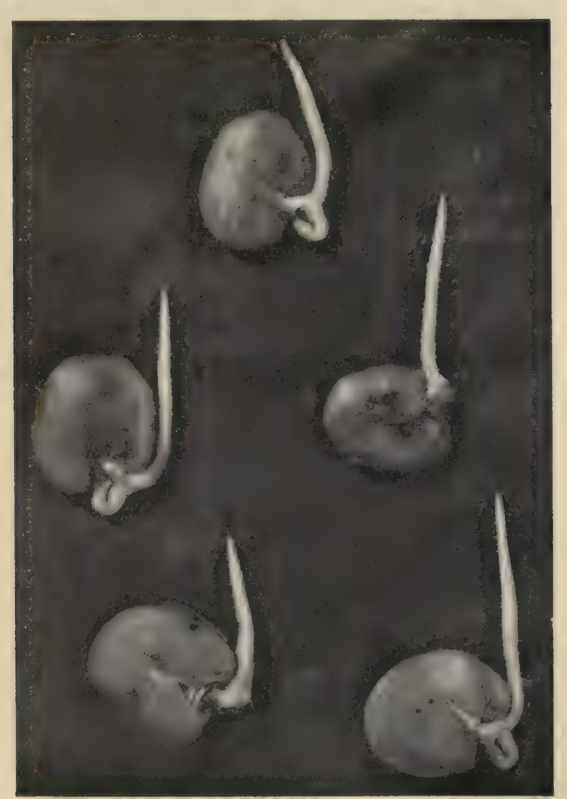

FIG. 1. Experiment to show the effect of gravity. A box is filled with damp sawdust and a sheet of blotting-paper is laid on the top. Soaked beans are then placed between the latter and the sheet of glass that takes the place of the lid. The box stands on end and when the roots are one or two inches long the whole thing is inverted as shown in photograph.

a dark and preferably rather warm press, and examine at intervals until results are clearly developed. After

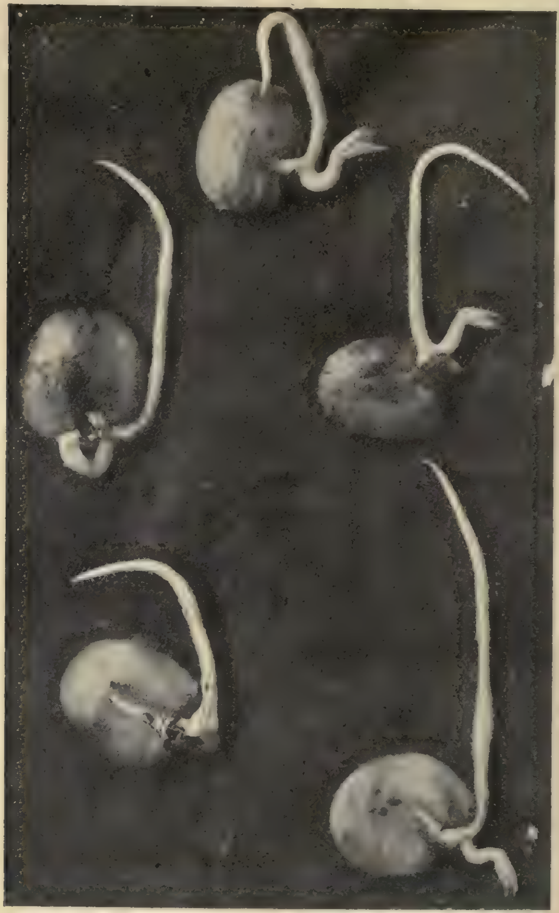

FIG. 2. Experiment showing effect of gravity. See Fig. 1. This photograph was taken after the beans had been inverted three days.

a few days the root will be found growing downwards, having by bending regained its former relation to gravity.

1. How soon did the root begin to turn?
2. In what part did the bending develop?
3. How long did it take to complete the bending?
4. How could we have a double bend?
5. What parts of plants grow naturally in the direction the root was placed in at the beginning of the experiment?
6. What parts have an intermediate relation to gravity—that is, a relation between that of the root on the one hand, and that of the parts suggested under No. 5 on the other?

It is evident that light, heat, and gravity all affect the plant, and each in a different way.

Causes of Germination. Let us now change the point of view. Instead of selecting factors in the environment and proving experimentally that each has some effect on the plant, let us fix on some particular result and attempt to discover to what it is due. It would hardly be possible to select a more important event in the life of a plant than just its sprouting from the seed, its first beginnings of independent existence, its germination. This happens when a seed is placed on the ground. Something then acts on it and out of the seed there springs a plant. Is the cause of this remarkable development hidden in the plant or is it something external that sets the wonderful changes agoing? Try the environment, of which, however, we must now take a more comprehensive view, including besides the three forces or forms of energy dealt with already, the material surroundings of the plant. Among the latter are soil, water, and air, representing respectively the solid, liquid, and gaseous states of matter. By the following experiment it is easy to determine the causes at work.

EXPERIMENT NO. 5.

Apparatus and Material.

One ounce of white mustard seed.

Five four-inch pots: dry soil for one pot and ordinary potting soil for the others.

One wide-mouthed bottle (or glass jar).

One plate (or flower-pot saucer).

A piece of flannel about three inches square (or sawdust or cotton-wool).

Bell-jars to cover the pots.

Sow the seed in the ordinary way in the dry soil and in three pots filled with ordinary soil. Sow also on the flannel, which must be made thoroughly wet and then laid on the plate or saucer. Finally, drop some seed into the bottle or jar amongst water and see that it goes to the bottom. Cover, where necessary, with a bell-jar to prevent the seed or the soil getting too dry. Keep the pot with dry soil, the one with ordinary soil, and the plate with the flannel in the light at the ordinary temperature of the room. The glass jar may be placed alongside. Put one other pot in a dark cupboard and another one where it will be exposed to low temperatures. (If it is the early part of the year it may be possible to keep this pot almost at freezing-point.) Examine the experiments at intervals and keep a record of the temperatures.

The results will show that air, water, and heat are necessary for germination. As gravity was acting in each case, we cannot from these results say it is unnecessary. In the meantime, however, let us assume that the seed would have developed into a seedling without its aid.

1. Show how the above conclusion is arrived at.

2. If it is objected that air has mixed with the water in the jar, how would you improve the conditions?

3. Suggest another arrangement for growing seeds without air.

4. What difficulties would a farmer experience if seeds could not germinate in the dark?

5. If seeds do not require darkness for germination, why should they be covered with earth when sown?

6. Why should seed not do so well in ground that is sodden?

7. Write a complete account of the above experiment, arranging the information under the following divisions: purpose, plan, setting-up, actual results, conclusions.

8. Show in tabular form the forces and materials acting on or at the disposal of the seeds in each section of the above experiment.

9. Finally, embody under a separate note any facts that have been observed in addition to those leading to the above conclusions.

Storage of Energy. We might wonder why light should not be necessary, and also why, while the gaseous and liquid parts of the material environment are indispensable, no solid matter seems to be so. A little reflection, however, may modify our view of the case. An effect may be due to light, although light may not be acting at the moment of the result. It may be said that a steam-engine does its work by the light of the sun, though not by the rays that strike the moving train. In a similar way the light of a previous season is used to promote the growth of a seedling. Germination can proceed only at the expense of the solid combustible material stored in the seed, and these materials were formed under the direct influence of the sun. So we see that, after all, germination could not take place without the help of light, though it is not the light that is shining at the time that counts.

The heat necessary to generate the steam is obtained by burning coal under the boiler of the engine. The coal itself is a result of the decay of prehistoric forests, whose trees accumulated their store of carbon compounds under the direct influence of the light that shone upon them in those distant days. Ever since then, the energy imparted by the light has been dormant in the coal. When it undergoes combustion, the long-pent-up energy is released and finds outlet in heat and power. The ancient light is utilized to drive the modern engine. In the same way this season's seeds germinate by last year's light, and this leads us one step farther. As the energy of the light is stored until it is required at the time of germination in some such form as starch, it may be claimed that matter in the solid state is as needful as the gaseous or liquid factors in the environment. In this connexion, however, we must admit that these accumulated stores of fuel, for such they may correctly be called, are in some cases actually inside the embryo before germination begins. Should this be so, strictly speaking they are part of the plant and not an item in its environment. The importance of such supplies, whether inside or outside the germinating plant, can easily be demonstrated.

EXPERIMENT NO. 6.

Apparatus and Material.

Two soaked beans.
Two pots of soil.

Take one of the beans and cut through the skin round half or a little more of the edge. Pull the plant out, separate the cotyledons, and with a sharp knife cut one of them off near its point of attachment, taking care not to injure the radicle or stem-bud. Replace the diminished embryo in the seed-coat again and plant it in one of the pots (No. 2). In the other pot (No. 1) plant another of the same size without removing any of its parts. Give equal treatment to each pot and after some weeks compare the plants.

If the seedling with two cotyledons shows a marked superiority in size and other respects over the seedling with one cotyledon, we shall be convinced of the importance of the stores of food (and of the light that made them possible) in the early stages of a plant's development. Besides noting generally that No. 1 is more vigorous than No. 2, detailed measurements may be made as shown in the subjoined table taken from an actual case.

	Plant 1.	*Plant 2.*
STEM.		
Height	17″	12″
Breadth of one side between 3rd and 4th foliage leaves	$\frac{1}{4}''$	$\frac{1}{6}''$
Internode between 6th and 7th leaf	$3\frac{3}{4}''$	$2\frac{1}{2}''$
LEAVES.		
Number of leaflets.		
3rd, 4th, 5th, 6th leaf	2	2
7th leaf	4	2
8th leaf	4	3
9th leaf	4	4

The experiments already described show that the plant is largely in the hands of the environment. It cannot begin active life without the necessary outside permission. Does the plant itself, then, count for nothing? Not at all. It is not absolutely at the mercy of the outside world. It can resist unpropitious conditions. It can struggle to adapt itself to circumstances.

Heat is necessary. Too much of it is bad, but the plant has some power of withstanding temperatures that are higher than usual.

EXPERIMENT NO. 7.

Apparatus and Material.

Four ounces of maize grains.
Four pots with soil.
Pan for boiling water.
Three bowls or other suitable vessels for soaking the grains.

Deal with the material as follows after dividing it into four portions:

1. Sow as they are.
2. Boil for 2 minutes.
3. Pour boiling water over them and leave them to soak in it for 24 hours.
4. Soak in cold water for 24 hours.

Sow all the four sets at the same time.

The results will possibly show that there is a limit to the heat that seeds will stand, but possibly also that they will stand a good deal more than they are ordinarily exposed to. Sets 1 and 4 will act as controls and may incidentally show the advantage of soaking seeds before they are sown.

When seeds are sown by a gardener, he puts them a little below the surface. The seeds of many wild plants germinate just where they fall. If this is the usual and natural way, will a seed that has by some accident been buried under a considerable weight of earth succumb to misfortune or be able by its innate energy to reach the realms of light and air?

Experiment No. 8.

Apparatus and Material.

Twelve selected beans (soaked).
Two large flower-pots with soil.

Sow six of the beans at the foot of one of the pots and fill in earth to the depth of a foot over them, making it fairly firm. In the second pot do likewise, but put the seeds only 6 in. below the surface.

The beans, if any reach the surface, may be taken out and examined for structural peculiarities they may have developed in the successful or unsuccessful effort to get up. For the sake of comparison it might be well to sow a third set just below the surface.

1. Is the arrival of the top of the bean at the surface due to the stem or the root?
2. Does the depth delay the appearance of the bean at the surface?
3. If so, does the delay bear any relation to the depth?
4. If the lowest beans are able to get into the air, are there any disadvantages in deep planting?
5. Describe the part of the plant between the seed-case and the surface of the soil.

The results of the experiments already described clearly show a very close relation between plants and their surroundings. It is impossible to understand the life of plants without a study of the conditions under which they exist. Some of these are discussed in greater detail in the following chapters.

CHAPTER II

THE BREATH OF PLANTS

THE experiments in the last chapter show that the plant is acted on by its environment. So, we may say, is anything. A stone on the beach is the plaything of the waves that toss it about and gradually wear it away by knocking it against other stones. We are apt to notice only the polish and the form thus given to it, but not to be overlooked is the fact that the stone is losing substance. It is unable to hold its own against the violence of the sea and the other destructive agencies that are continually at work. How different with the plant. It too has a struggle with its surroundings. The environment does not treat it considerately. It is made hot, it is made cold, it is made wet, it is made dry, by turns, not to speak of the lashing it gets at the hands of the wind. Yet the plant comes up smiling through it all. It is winning in the struggle, and this is plain to see, for it is actually getting bigger, though acted on by the same forces that make the stone become smaller. Why is this? Simply because the stone is dead matter and the plant is a living thing. Life makes all the difference. How can we prove that the plant is as really alive as an animal? By comparing it with an animal and finding resemblances that we do not at first suspect.

EXPERIMENT NO. 9.

Apparatus and Material.

One ounce of white mustard seed.
Stoppered bottle of about 8 or 10 oz. capacity.

Soak the seed one night and after removal of superfluous moisture place it in the bottle to a depth of say 1 in. Stopper the bottle and leave it in a warm place out of the light. After a couple of days introduce into the bottle a small quantity (1 or 2 oz.) of lime-water. Replace the stopper and shake.

Result.—The lime-water[1] becomes milky.

Conclusion.—The seed has had some effect upon the air.

1. How would you prove that air that has not had seed in contact with it does not give the same result?

2. We speak of the air being changed. What sort of change or changes might occur in the circumstances?

3. If when lime-water is shaken up with ordinary air the same result is only slightly perceptible, what conclusion would you draw then?

4. If seeds soaked as above are immediately shaken up with lime-water and no milkiness appears, what conclusion may be drawn?

5. If the soaked seeds are brought to the boil before being put in the bottle and no milkiness appears, draw still another conclusion.

6. Why would you not expect this experiment to work with dry seeds?

With the above experiment, compare the results of the following one.

---

[1] See Appendix E.

EXPERIMENT NO. 10.

Apparatus and Material.

Glass tube a few inches long.
A small quantity (2 oz.) of lime-water in a beaker or bottle.

Blow through the glass tube into the lime-water for a minute or two until the lime-water turns milky just as in the former case.

The results are the same in each of the two experiments. As ordinary air will not cause the milkiness, the air we breathe in must undergo some change in the lungs before being breathed out. This change must be identical with the change that occurred in the case of the mustard seed. The operation which causes the change in the case of animals is called breathing or respiration, and the only conclusion we can form is that the same process goes on in plants, or at least some process that ends with the same result. Now, as long as an animal breathes we say it is alive. When it permanently stops breathing it is dead. In the case of animals, therefore, breathing is a proof of life. May we conclude that because plants produce the same effect on air as animals they also are alive. Before deciding this question, let us consider in more detail the effects that animals and plants produce on the air.

If a room is packed full of people, their breath has a very bad effect upon the air, which soon becomes polluted and eventually poisonous. Bad air also occurs under other conditions. It is found in old wells and in vaults and in coal-mines after explosions. In each case a gas is present which does not occur except to a very small extent in fresh air. This poisonous addition to the atmosphere is known by miners as choke-damp, and its scientific name is carbon dioxide.[1] This is the gas produced in the bottle by the soaked mustard seed in Experiment No. 9, and it is the gas given off by all plants. It is therefore very necessary to be acquainted with this gas if we are to understand the processes that go on inside plants. We must find out the properties of carbon dioxide.

However bad the air in a room or at the bottom of a well may be, it will be found to consist of the constituents of ordinary air in addition to the gas we wish to examine. In order, therefore, to get a quantity of it by itself (that is, without admixture of other gases) we must make special arrangements.

EXPERIMENT NO. 11 (Fig. 3).

Apparatus and Material.

A few marble chips.
Hydrochloric acid diluted with water.
Glass tubing.
One thistle funnel.
One flask (or bottle).
Two-holed rubber stopper to fit it.
Bath with perforated shelf.
Several cylindrical jars (or wide-mouthed bottles).
Glass circles big enough to cover the mouth of the jars or bottles.

Fit the parts together as shown in the figure. Put the marble chips in the flask (or bottle), pass thistle funnel and bent end of glass tube through the holes of the stopper, which is then firmly placed in the mouth of the flask. Fill the bath with water enough to cover the shelf and rest on the latter an inverted jar full of water.

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[1] See Appendix F, under Carbon dioxide.

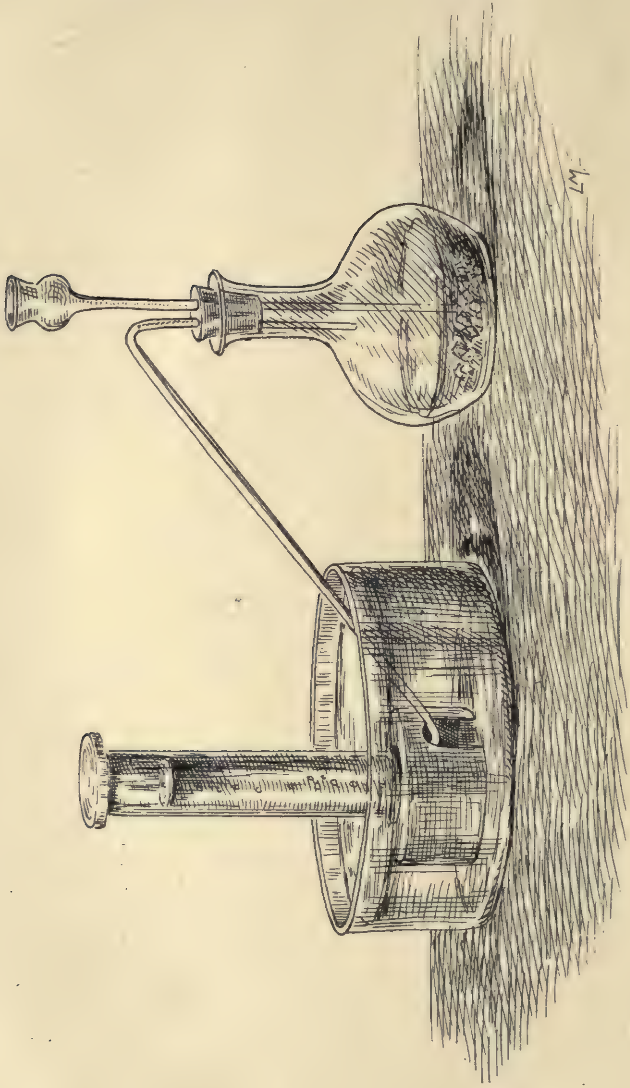

Fig. 3. Preparation of Carbon dioxide.

Bring the end of the bent tube just below the hole in the shelf. Now pour in a small quantity of the acid.[1] Effervescence immediately takes place. This is the gas forming. It will soon pass along the tube and rise in bubbles in the inverted jar, displacing the water. When full, cover the mouth with one of the glass circles and remove the jar to the table. Fill several jars in the same way and then apply the following tests. Before doing so, put lime-water into one of the jars and shake it up with the gas, and thus make sure that it really is the same as was produced by the germinating mustard seeds. Then deal with the other jars.

1. Plunge a lighted taper or splinter of wood into one of the jars. If this can be done several times with the same result in the same jar, what conclusion may be drawn as to the weight of the gas?

2. Shake up a jar full of the gas with a little water and drop in a piece of blue litmus-paper. If the paper turns red, it shows that the gas when mixed with water gives an acid reaction.

3. Fit a rubber stopper into a test-tube containing a little water in addition to the gas. Remove the stopper under water and introduce half an inch of a stick of caustic potash. Replace the stopper and allow the caustic to dissolve. By gently moving the tube let the solution mix with the gas. Open under water (with the tube erect and inverted), when the result should enable you to draw a conclusion as to the effect of the caustic solution on the gas.

4. Repeat the last experiment, but without the caustic. After getting a result, go through the process again and see if the result can be increased. Compare the effect of water on the gas with that of caustic solution.

---

[1] See Appendix F: Acids.

5. Write a full account of the results and conclusions, giving numerical details where possible.

We have now seen that carbon dioxide is formed by plants and animals, and also by the action of hydrochloric acid on marble or chalk. Take another case of its production.

EXPERIMENT NO. 12.

Apparatus and Material.

Candle on stand.
Plate.
Bell-jar.

Place the candle with some support in the middle of the plate and pour water round it. Light the candle and put the bell-jar over it. At first there is almost no water inside the jar. What happens?

1. The water rises.
2. The inside of the bell-jar becomes dim.
3. The candle goes out.

Various questions may now be asked.

1. What does the deposit on the inside of the bell-jar consist of?
2. Does the water rise at a uniform rate?
3. If not, when does it rise quickly, when slowly?
4. What is there less of in the jar at the end of the experiment?
5. Why should the smoke go upwards after the flame goes out?
6. If there happens to be some water at the foot of the jar at the beginning of the experiment, what cause is at work that would tend to press that water out?
7. How could it be arranged to have water to the depth say of an inch inside the bell-jar at the start?

8. If it is suggested that the deposit on the jar is really water that has been transferred from the plate, how could the experiment be altered so that, if the dimness still comes on, it could not possibly be attributed to such a cause?

9. What is the object of putting the water in the plate at all?

10. How long does the candle remain alight?

Exercises.

1. Carry out what you suggest under question 8.

2. Try the experiment with jars of different size and determine the effect on the length of the time the candle remains alight.

3. Do the experiment twice with the same jar, first with the candle near the foot, but not low enough to be covered with water, and second, with the candle high up in the jar, and see whether the candle remains alight for an equal number of minutes each time.

Leaving the other matters alone for the present, let us consider the most obvious of all the results—the effect on the candle. The conclusion from this is that the air has been changed. If it had remained as it was at first, the candle would have gone on burning. In the case of the mustard seed in the closed bottle we also came to the same conclusion—that the air had undergone a change. Is the change the same in each case. That can be settled easily and quickly.

Experiment No. 13.

Apparatus and Material.

Small piece of candle.
Wide-mouthed bottle.
Two corks, one to fit the bottle and another smaller one.
Lime-water.
Piece of stiff wire.

Connect the two corks by putting the wire through them. Fix the candle by melted grease on to the upper side of the smaller cork. Light the candle and lower it into the bottle, keeping the mouth closed by the larger cork. When the candle goes out, remove it gently without disturbing the bottle. Then pour in lime-water (about an ounce), close the mouth of the bottle and shake. Result—the lime-water becomes milky. Conclusion—the candle has produced carbon dioxide. We have arrived then at the really important fact that animals, plants, and the burning candle all give rise to carbon dioxide. The result is the same in all three cases. Is the process by which the result comes the same? There seems nothing in the case of the plant to correspond to the heat and light evolved by the candle when it is burning—that is, when it is giving off the gas in question, but the processes at work in the two cases are more alike than might be at first suspected, as the following experiment will show.

EXPERIMENT NO. 14 (Fig. 4).

Apparatus and Material.

Three bell-jars.
Three battery-jars.
Three thermometers, graduated in fifths or tenths.
Barley, in three conditions, as follows:
    No. 1. Soaked for forty-eight hours or more.
    No. 2. Soaked for same time, then boiled for a few minutes, and of course allowed to cool.
    No. 3. Dry barley.
There must be enough of each to fill a battery-jar.

By means of a sieve (or otherwise) run off the water from No. 1 and No. 2. Fill a jar with each of them and another with No. 3 and place them all on a tray together. Cover each jar with a bell-jar, with the thermometer passing down through the tubulus till the bulb is well sunk in the barley. Fill up the tubulus with cotton-wool

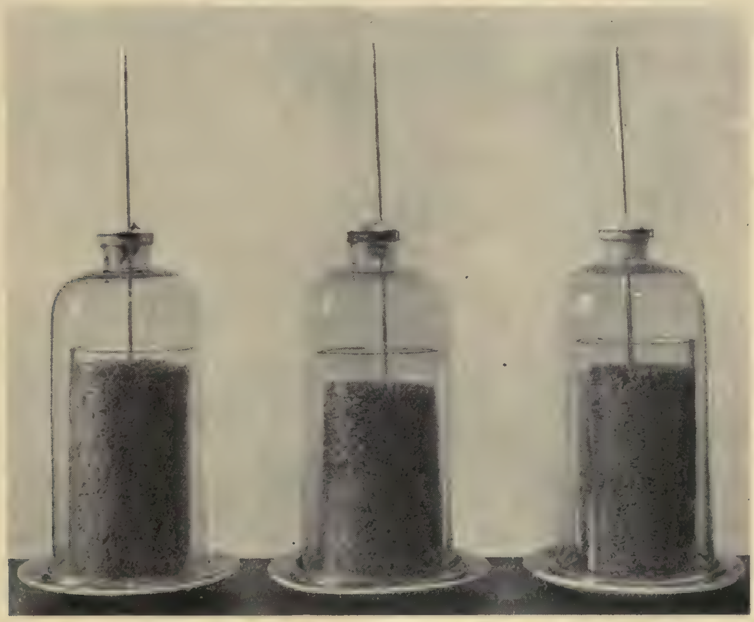

FIG. 4. Experiment to show rise of temperature due to respiration. The jar to the right contains grain that has been soaked, the middle jar contains grain that has been soaked and then boiled to destroy vitality, and in the jar to the left the grain is dry.

placed round the thermometer. After all has been arranged, allow some time to elapse and then take readings at intervals and tabulate them. After a distinct difference has been established between the readings of No. 1 and No. 2, or between No. 1 and No. 3, remove the tray with the three jars to another position where the temperature is distinctly lower and take another set of readings. Finally, if a much higher temperature is available, say in a hothouse, remove the whole apparatus there and take a further record. The list of readings may be afterwards plotted on graph paper.

This experiment ought to show that the living grains, which alone can breathe, generate heat, and the thermometer in No. 1 should register one or two degrees more than the others.

Compare results with the following obtained in a similar experiment:

TEMPERATURES (CENTIGRADE).

	1	2	3	4	*Differences*		
Time.	*Soaked.*	*Boiled.*	*Dry.*	*Air of room.*	*between* 1 *and* 2.	*between* 1 *and* 3	*between* 1 *and* 4.
10.5	20·6	17·1	17·4	18·2	3·5	3·2	2·4
10 25	20·6	17·1	17·4	17·2	3·5	3·2	3·4
10.40	20·9	17·2	17·5	17·1	3·7	3·4	3·8
11	20·8	17·2	17·5	17·6	3·6	3·3	3·2
11.35	20·9	17·4	17·6	18·2	3·5	3·3	2·7
12.40	20·8	17·6	17·6	18·6	3·2	3·2	2·2
1.12	21·4	17·8	17·8	18·6	3·6	3·6	2·8
1.30	21·4	17·8	17·9	18·4	3·6	3·5	3
1.45	21·5	17·9	18	17·4	3·6	3·5	4·1
1.50	21·5	18	18	13·8	3·5	3·5	7·7
5	18·4	15·6	15·1	13·4	2·8	3·3	5

In this case the grain used was oats. At 1.47 the tray with the experiments was moved to a cooler position near a big window. The interest of the experiment would have been increased if after the above entries were made additional readings could have been taken with the temperature of the air just a little above freezing-point, but as it is the fact is evident that the soaked grain maintains a higher temperature than the boiled or the dry.

1. Account for the higher temperature of the soaked grain.
2. What prevents the boiled grain acting like the soaked?
3. Answer the same question with regard to the dry grain.
4. Account for (1) the small difference in the last column at 12.40, (2) the big difference (7·7°) at 1.50, and (3) the reduction of that difference by 5 o'clock.

Any ordinary fire exemplifies the same process as a lighted candle. The action that goes on, whether it is a candle-wick or a piece of coal or a stick that is ignited, is known as burning or combustion. In the body of every living plant or animal a chemical action is going on that may strictly be compared to this. A slow burning is going on—so slow in the case of the plant that it is generally difficult to detect the increase of temperature occasioned by it. In the higher animals the process is more active, and as a result their bodies are distinctly warm—not so hot certainly as the flame of a candle, but still much above the average temperature of the atmosphere in this country. Especially must we note that whenever heat is produced in this way, carbon dioxide is also being formed. We put this in a general form and say that when plants breathe (that is, give off carbon dioxide) they generate heat just as a candle does when it burns.

It may be objected that in the foregoing experiments it has only been shown that seeds give off carbon dioxide and that possibly full-grown plants act otherwise. The matter can be settled by trial with parts of fully-developed plants.

EXPERIMENT NO. 15.

Apparatus and Material.

Fresh twigs.
Two bell-jars.
Two plants.
Two small bottles.
Lime-water.

Put one or two twigs with their stalks dipping into a bottle of water on a plate, on which also place a small beaker containing lime-water. Over all put a bell-jar. Set up a control identical with the foregoing but without any twigs. Place both in the dark for a day or two. If at the end of that time the water beside the leaves shows signs of milkiness, and the lime-water inside the other bell-jar does not, that will be proof that a leafy twig breathes just as germinating seeds do.

Experiments like some of the foregoing, showing only the kind of gas produced, are known as *qualitative*. Those which show the exact quantity of gas produced under accurately ascertained conditions are known as *quantitative* experiments. The following is only of a roughly quantitative nature, but will give some idea of what is meant by such an experiment. We shall find that even a small number of peas exhale a considerable amount of the gas we are discussing.

EXPERIMENT NO. 16 (Fig. 5).

Apparatus and Material.

Soaked peas.
Respiration-tube fitted with solid rubber stopper.
Wide-mouthed bottle or metal stand.
Caustic potash.
Inch or millimetre scale.
Graduated measuring-glass.

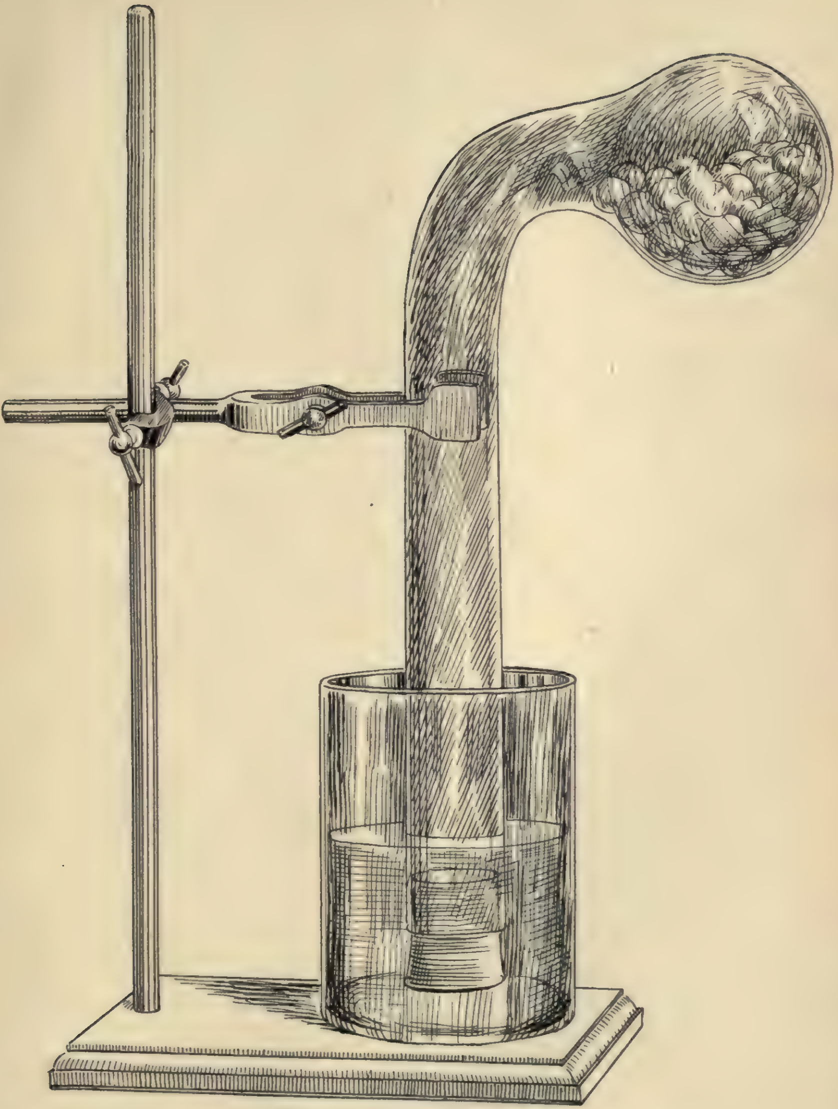

FIG. 5. The carbon dioxide given off by the peas accumulates in the respiration-tube and the approximate volume of it can be found.

Remove surface moisture from fifty soaked peas and place them in the bulb of the respiration-tube. Put in stopper firmly and support the tube in the bottle or by a metal stand. Put the whole in the dark and examine after two days, dealing with the experiment as follows, using a pneumatic trough or other convenient vessel for holding the water required :

1. Remove stopper under water, noting whether there is any inside pressure tending to drive the stopper out.
2. Replace stopper, keeping mouth of respiration-tube under water all the time.
3. Keep the tube perpendicular and measure the height, if any, to which the water rises above the stopper.
4. Remove stopper and run out the peas under water.
5. Replace stopper and measure the height of the water now. The increase of water represents the volume of the peas.
6. Again remove the stopper and slip in 1 in. of caustic stick and replace stopper.
7. Allow the caustic to dissolve and then gently move the tube so that the solution mixes with the gases in the tube.
8. Remove stopper and when the rush of water has stopped replace it.
9. Measure the height of the water in the tube. The additional rise shows how much carbon dioxide the peas formed in the respiration-tube.

In order to bring the results to numerical form, find—

1. Capacity[1] of the tube minus the space occupied by the stopper.
2. The space occupied by the peas and any water that may have come in before the peas were run out.

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[1] See Appendix C : Areas and volumes.

3. The amount of the gas absorbed by the caustic solution—that is, the amount evolved by the peas.

4. The proportion that this bears to the original amount of available air.

Tabulate your results and compare with the following:

Capacity of the respiration tube . . = 350 c.c.
Volume of peas . . . . . = 50 c.c.
∴ available air . . . . . = 300 c.c.
Height of water in tube:
(1) After removing peas . . . = 2·8″
(2) After absorption of the gas . . = 6·8″
Difference in level owing to absorption of gas . . . . = 4″
Calculated volume of gas absorbed . = 70 c.c.
∴ percentage of original volume of gas changed into carbon dioxide . = 23 %

These results must be taken only as approximate, especially if some gas escapes at the first removal of the stopper.

The following experiment is intended to give some idea of the amount of gas evolved in a given time. Unfortunately it is rather uncertain in its working, but affords good practice in setting up, and under favourable conditions gives interesting results. It is also of use in showing how careful it is necessary to be in drawing conclusions when some other cause (in this case temperature) is at work as well as the one that is being specially dealt with.

EXPERIMENT NO. 17 (Fig. 6).

Apparatus and Material.

Four tubes about 18 in. or a little more in length, with an upper portion with a bore of about $\frac{3}{4}$ in., and a lower portion with a bore of 3 to 4 millimetres.
Caustic solution.
Four test-tubes.
Soaked peas.
Four rubber stoppers to fit wide end of the tubes.
Four crystallizing dishes.
Four stands.
Finely graduated thermometer.
Tall jar containing coloured water.

Put twenty-five peas in the wide upper portion of each long tube, and beside them put, in two cases, a test-tube of strong caustic solution and in the other two a test-tube of ordinary water. Having arranged all this, let one of the tubes down into the tall jar containing plain or coloured water. Now put rubber stopper in place and remove the whole thing to its former position where the lower end rests in crystallizing dish, and the upper part is secured by the clamp. Do the same with the other three long tubes. If the columns of liquid in the narrow portion of the long tubes do not each reach to the same level, adjustment may be made by twisting in one or more of the stoppers a little way. With a little seccotine attach a scale to the narrow portion of each tube and after a few minutes begin taking frequent readings of the height of the columns 1, 2, 3, and 4. Temperature must also be accurately recorded each time. The tubes with water only in the test-tube beside the peas are intended to act as controls.

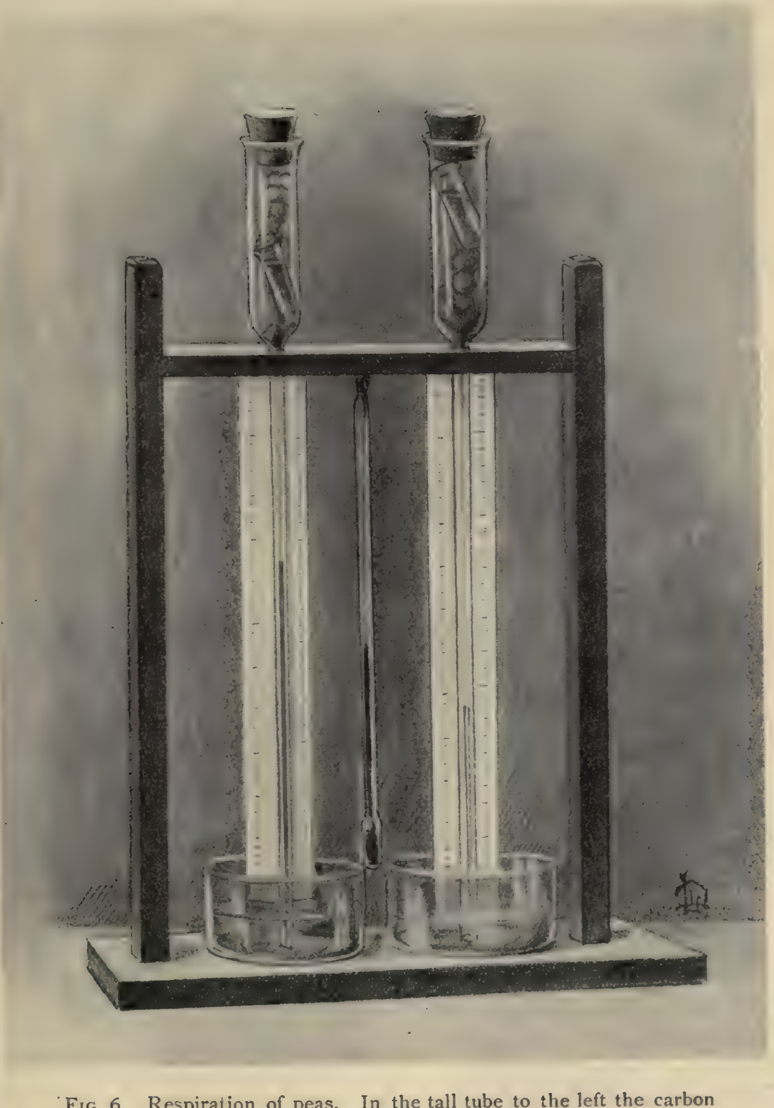

FIG. 6. Respiration of peas. In the tall tube to the left the carbon dioxide is absorbed by strong caustic solution in the test-tubes. The test-tube in the other tall tube contains only water.

The experiment can, of course, be set up with only two long tubes—one with caustic solution and one without.

Tabulate results fully and compare with those given in the subjoined list of readings.

READINGS FROM RESPIRATION EXPERIMENT.

Time.	*Temperature (Centigrade).*	*E.* 1.	*C.* 1.	*E.* 2.	*C.* 2.
12.30 p.m.	18·5	29	36	75	77
12.35 ,,	18·2	35	37	76·5	76
12.40 ,,	18	38	35	78·5	74
1 ,,	19	40	24	78	61
1.5 ,,	18·8	44	25	78	57
1.10 ,,	18·8	46	21	79	53
1.15 ,,	17·9	55	27	86	59
1.20 ,,	16·7	65	35	96	67
1.25 ,,	16·9	70	35	99	68
1.30 ,,	17·8	69	32	97	63
1.35 ,,	18·2	68	24	95	55
1.40 ,,	17	79	33	103	60
1.45 ,,	14·9	104	54	125	84
1.55 ,,	17	90	31	114	62
3.20 ,,	15·5	136	34	147	46
4.25 ,,	14·8	174	41	175	42
4.35 ,,	14·8	179	42	179	42
4.45 ,,	14·8	185	44	184	43
4.55 ,,	14·8	192	46	189	44
5.5 ,,	14·5	196	46	193	43

The numbers in the last four columns show the height in millimetres of the liquid in the narrow portion of each tube. E. = experiment, C. = control.

Make graphs[1] of the readings given above and also of your own readings. Answer the following questions:

1. Why should the other curves rise when the temperature one falls?

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[1] See Appendix D.

2. Show that the curves after 1.55 exhibit the results of respiration better than the earlier parts.

3. Why are the control curves (in their later portions) so much more nearly horizontal than E. 1 and E. 2?

4. Judging by E. 1 and E. 2, what can you say of the respiration between 1.55 and the end of the experiment?

Controls such as are arranged in Experiment 16 are often so necessary that special attention is drawn to their importance. An illustration of the need of them is given by an experiment shown in Fig. 7. The arrangement is intended to show the rate at which the enclosed peas give off carbon dioxide. As the gas is evolved it may be at once absorbed by strong caustic solution inside the bottle but kept separate from the peas. The absorption of the gas will cause a rise of the coloured liquid in the left arm of the bent tube, and this rise ought to be in proportion to the amount of carbon dioxide formed. But temperatures may seriously interfere with the readings on the scale. If the air of the room gets colder the air inside the bottle will contract and in doing so will add to the rise caused by the absorption of carbon dioxide, and we shall be unable to apportion to each cause its proper share of the result. A control must be set up without peas, but in all other respects a copy of the experiment itself. If now there is a rise of 10 millimetres in the control and 25 in the experiment, it is evident that only 15 of the latter are to be laid to the account of the peas. In this way we can check our results, and the *control* of the conclusions thus secured has suggested the name given to these most indispensable adjuncts of many experiments.

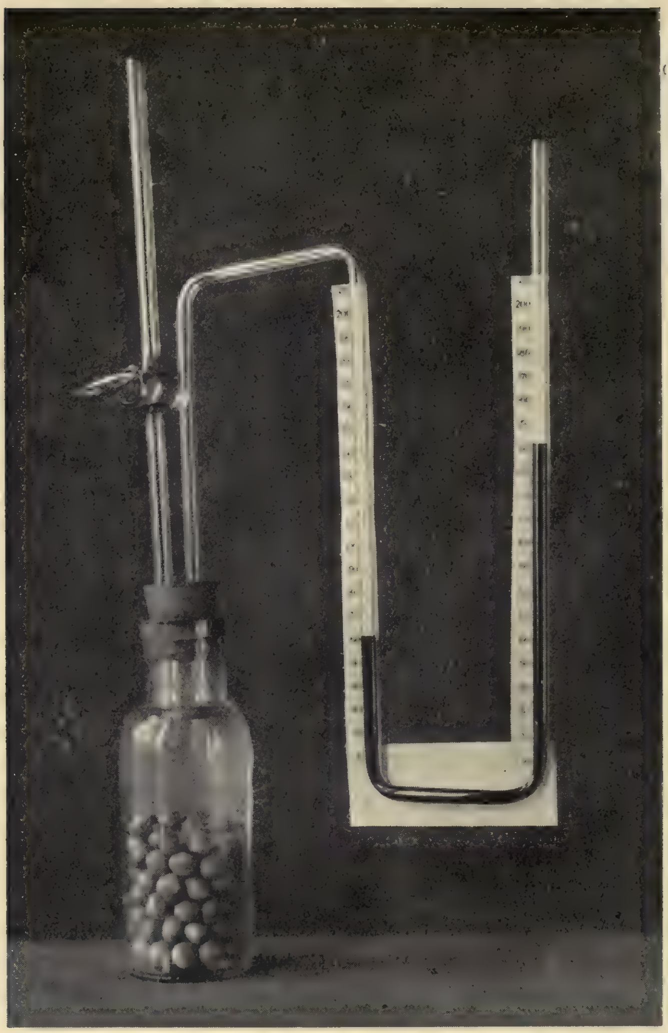

FIG 7. Example of an experiment which must have a control going at the same time. Otherwise change of temperature may obscure any result due to the respiration of the peas. To make this illustration tally with the description given on page 43 an alteration must be made in the arrangement shown. The caustic solution must occupy the lower portion of the bottle, and to keep the peas clear of it they should be suspended in a muslin bag.

1. The absence of peas will mean more air in the control. How would you equalize the volumes?

2. What objection is there to the volumes of air being unequal?

3. If the air of the room was getting warmer how would the readings be affected?

4. How would you deal with them in that case?

The preceding experiments show:

1. That plants agree with animals in giving off carbon dioxide.
2. That both plants and animals agree with the burning candle in the above respect, and also resemble it in showing a rise of temperature while the process of giving off the gas is going on.

Further note that in experiments like No. 15 the quantity of gas produced is considerable, even when only a small quantity of peas is concerned. What must the amount be when we take into account the vegetation of the world, which through uncounted centuries has been discharging carbon dioxide into the air. Why has this long-continued pollution not made the air too bad for animals to breathe.

Before answering this question, we shall in the next chapter first discuss the atmosphere, so as to be able to say definitely what part it plays in the breathing of plants (and animals). Is it simply a receiver of the carbon dioxide that plants and animals need to get rid of, or does it actually assist in the production of that gas?

CHAPTER III

THE NEED FOR OXYGEN

In the previous chapter it was shown that the plant has an effect on the atmosphere as it discharges into it the gas that results from breathing. Let us now ask—Has the atmosphere any effect on the breathing of the plant? Can the plant breathe without the atmosphere? In order to be able to answer this question it is necessary to find out of what the atmosphere is composed. This, in a general way, is easily done.

Experiment No. 18.

Apparatus and Material.

Iron filings.
Test-tube.
Stand and clamp.
Wide-mouthed bottle.

Wet the inside of the test-tube and then put in some iron filings. These will readily adhere to the damp side of the tube. Invert it and fix it in this position with the mouth dipping a little into a bottle of water. Next day it will be found that the water has risen in the test-tube and it will go on rising until it occupies roughly the lower fifth of the tube. Farther than this it does not go, however long it is allowed to remain.

One fact is clear. A certain amount of space previously occupied by air, or by some gas present in air, is now occupied by water. What has become of the gas? We might suggest three possible explanations:

1. The air in the tube has got compressed.
2. Some of it has got absorbed by the water.
3. It has been used up to make something else.

The first is not very likely to be the correct explanation for the simple reason that, as the tube dips into the water only a little way, the air inside is not subjected to much more than ordinary atmospheric pressure. The second suggestion seems reasonable, but there is nothing obvious that would help to prove it true. One thing, however, is perfectly clear, and that is that the iron filings are not in the condition they were in at the start of the experiment. A red substance is noticeable on their surface. This looks like rust. It is evident that something new has been formed. Perhaps the gas has been used up in the formation of this. If so, some of the steel must have been used up too, for the new substance is certainly not made of the gas alone, otherwise it would not be solid. Nor can it be made of the steel alone, otherwise it would not be red. It is likely, then, to be a compound of them both.

Why did the water stop rising? Surely because the formation of the new compound stopped. A shortage of raw material would account for this. There was still steel left. It was therefore the gas that had been used up. The gas that still occupies four-fifths of the tube must be of a different kind.

Air, therefore, consists of at least two gases:

1. A gas that contributes to the formation of rust.
2. A gas (or gases) that takes no part in this process.

Let us now go a step farther.

EXPERIMENT NO. 19.

Apparatus and Material.

Iron filings.
Cylindrical jars.
Pneumatic trough, &c.

Repeat the former experiment, but use jars instead of the test-tube. In a day or two after the water has risen to the usual height, run off (under water in the pneumatic trough) the gas that remains into several smaller jars. Test this gas by putting in a lighted splinter. The latter is immediately extinguished. From this we might conclude that the gas is no other than carbon dioxide, but if a second jar is taken and lime-water is added and shaken up with the gas, no milkiness is produced. We therefore conclude that, after all, carbon dioxide is not present.

As a matter of fact, this gas we are testing is really nitrogen, which is known to form, as our experiment suggests, about four-fifths of the ordinary atmosphere. We might reasonably expect a gas found in such quantity to be very greatly used by plants, just as water, which is also almost everywhere on the surface of the globe, is indispensable to vegetation, by which, as every one knows, it is used in large quantities. In the meantime, however, we shall be content with noting that this gas seems to have rather negative properties. Like several common gases it has no smell and no colour, but unlike these it is slow in acting on other substances and is not easily acted on. It does not burn itself and it does not help other things to burn. It has no effect on lime-water. With this we have done with nitrogen,[1] for the present.

[1] See Appendix F: Nitrogen.

It is evident that the power ordinary air has of supporting flame is due not to the inert though plentiful nitrogen, but to the other gas which is withdrawn from the air when rust is formed—that is, to oxygen.[1] Let us now examine this active and important gas.

EXPERIMENT NO. 20 (Fig. 8).

Apparatus and Material.

Chlorate of potash.
Black oxide of manganese.
Pneumatic trough.
Cylindrical jars.
Glass circles.
Mortar and pestle.
Splinters of wood.
Strong glass test-tube with cork (1-holed) to fit, and bent glass tube of wide bore.

Mix well and pound in the mortar a small quantity of the chlorate with a smaller quantity of the oxide of manganese. Transfer the mixture to the test-tube. Support the tube by a metal stand. Apply heat cautiously, and by means of the delivery tube conduct the gas given off to the pneumatic trough and collect it in the usual way.

The gas thus prepared is oxygen. Slip the glass cover from one of the jars plunging into it a glowing splinter. This will immediately burst into flame. Withdraw it at once, blow it out, and plunge it into the jar again. Try how many times this can be done with the same result. If this can be done often, we may safely conclude that oxygen is not a particularly light gas, otherwise it would escape from the jar before we could put in the splinter a second time.

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[1] See Appendix F: Oxygen.

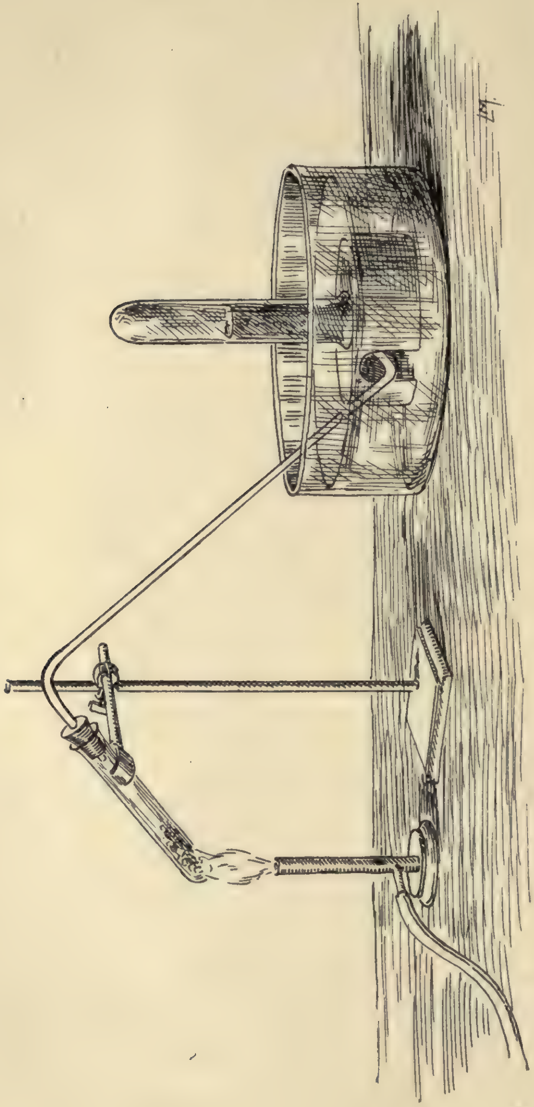

FIG. 8. Preparation of Oxygen.

The atmosphere, then, consists of at least two gases very different in properties—nitrogen, which does not support combustion, and oxygen, which does. In the meantime we leave out of account carbon dioxide, which occurs only to the extent of about three parts in 10,000, and also some other gases more recently discovered, which are always present.

Combustion. Consider again the familiar example of the candle. When it burns there are the following results:

1. Light.
2. Heat.
3. Waste of the candle.
4. Waste of the oxygen.
5. Formation of new substances.

1. If the candle is allowed to burn some time, it becomes evident that it has got smaller. How would you show that it is losing substance every minute?

2. How would you prove that oxygen gets used up?

3. How would you show that carbon dioxide is not present to any appreciable extent before the burning begins?

4. How would you prove that it is present in quantity after the burning has gone on for some time?

In the above list of results, the most noticeable one is put down first and the most important one last. This is the formation of new substances, one of which is carbon dioxide. How does oxygen help to bring this about? We know that oxygen, in the usual phrase, supports combustion, in other words, contributes to the burning. This fact is clear enough. Increase the proportion of oxygen and the flame gets brighter. Diminish the quantity available, the flame gets less. Cut off the supply altogether and the flame is at an end. This is perfectly evident, but still we have not yet answered the question, In what particular way does oxygen assist? We have only got the fact that it does so.

Chemical union. Now it is impossible fully to understand the nature of burning or breathing without consideration of what is meant by a chemical compound. No better example of such could be got than one of the commonest and most useful of substances, namely, water.[1] Its chemical formula—H_2O—shows that it is composed of twice as many atoms of hydrogen as of oxygen. Fill a jar two-thirds full of hydrogen and add oxygen to occupy the remaining third. Suppose the jar is perfectly dry inside and contains nothing but the two gases. These will not remain at separate ends of the jar, but get mixed, and we may then say that the jar contains a mixture of oxygen and hydrogen, which, though mixed, still retain their own special properties and occupy space equal to the sum of their separate volumes. If an electric spark is passed a sudden change occurs. The jar which was previously quite dry has now got a little liquid on the inside. This is not liquid hydrogen or liquid oxygen, but a compound of them both, namely water. By the application of ordinary heat this water may be made to pass into the gaseous form, but it does not turn back into oxygen or hydrogen. This can easily be shown. If a light is held to a jar of hydrogen, the hydrogen takes fire, in other words, burns. Do the same to a jar of oxygen and although the oxygen itself does not burn, the taper that is plunged into it bursts into bright flame. Now take a vessel filled with the compound of oxygen and hydrogen in a gaseous form (steam), and plunge a lighted taper into it. This time nothing burns, neither the gas itself nor the taper, for the latter is immediately extinguished. Thus the compound has properties that are different from the properties of either of the simple bodies of which it is formed. This formation of compounds out of elements is known as chemical union, and is often accompanied by the generation of heat and sometimes even by light.

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[1] See Appendix F, under Water.

In the above experiment the elements are made to unite and form the compound. The composition of water is therefore proved by *synthesis*. By the converse method of *analysis* we may arrive at the same finding. Instead of beginning with hydrogen and oxygen and producing water we begin with water itself and analyse it—that is, break it up into its component parts. For this purpose the aid of electricity is again called in and two wires from a battery are introduced into a vessel containing acidulated water. Each wire ends in a small metal plate and above the plates test-tubes are fixed in an inverted position. The test-tubes are full of water, and when the current is turned on the decomposition can be seen going on as the hydrogen displaces the water in one of the test-tubes, while the oxygen collects in the other.

Let us now return to the compound with which we are specially concerned—carbon dioxide. Its chemical formula is CO_2, showing that it results from the union of one part of carbon with two of oxygen, but when the compound is formed its gaseous volume is no more than that of the constituent oxygen.

It is now surely clear why oxygen is so necessary. When burning takes place there is light and there is heat, but most important of all is the chemical union by which the new substance is produced. The new substance in this case is carbon dioxide, which cannot possibly be formed unless both the elements of which it is composed are present. One of these is carbon and the other oxygen. Both elements are absolutely essential if a candle or a fire is to burn, and equally necessary if a plant or an animal is to breathe. The resemblance between burning on the one hand and breathing (whether of plant or animal) on the other is much closer than at first appears, as is shown by the following details:

1. The product is the same in each case—carbon dioxide.
2. The oxygen, without which none of the processes can go on, is in each case derived from the same source—the atmosphere.
3. In all the cases heat is generated—much in the case of the candle, less by the breathing of the animal, and still less in the case of the plant.
4. The carbon is supplied from the substance of the candle, from the food absorbed in the blood by the animal, and by carbonaceous material in the cells of the plant.
5. There is also a process of waste—clearly seen in the candle, but obscured in plants and animals by the converse process of feeding. The wastage is due to the fact that the carbon that previously formed part of the thing breathing or burning is now part of the carbon dioxide given off, and is thus lost to the candle, plant, or animal.

From No. 2 it is evident that if breathing or burning is to go on in a closed space provision must be made for a supply of fresh air. How that can be done is shown in the following experiment with germinating peas.

EXPERIMENT NO. 21 (Fig. 9).

Apparatus and Material.

Soaked peas to fill the U-tube.
One large bottle.
Three conical flasks.
One U-tube.
Two 1-holed rubber stoppers for the U-tube, and
One 2-holed stopper for each of the other four vessels.
Glass tubing.
Lime-water.
Caustic potash.
One clip.
Small piece of rubber tubing.

Put the apparatus together as shown in the figure. The glass tubing must be cut[1] into suitable lengths and bent.[1] Flask 1 (to the right) contains caustic solution. Flasks 2 and 3 contain lime-water. The peas are put in the U-tube and the large bottle is filled with ordinary water. The outer tubes are tapered[1] to a small orifice. Notice also that a piece of rubber tubing is interposed beyond the bottle to admit of a clip being used. When all has been fitted together, suck the water into the long tube leading from the bottle to the beaker. As the water runs out air is pulled in. The only possible point of entrance is the end of the tapered tube at the extreme right, and so, on its way to fill the place vacated by the water in the large bottle, the air thus admitted must travel in succession through flask 1, flask 2, the U-tube, and flask 3. A piece of apparatus used like

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[1] Appendix E: Practical Hints.

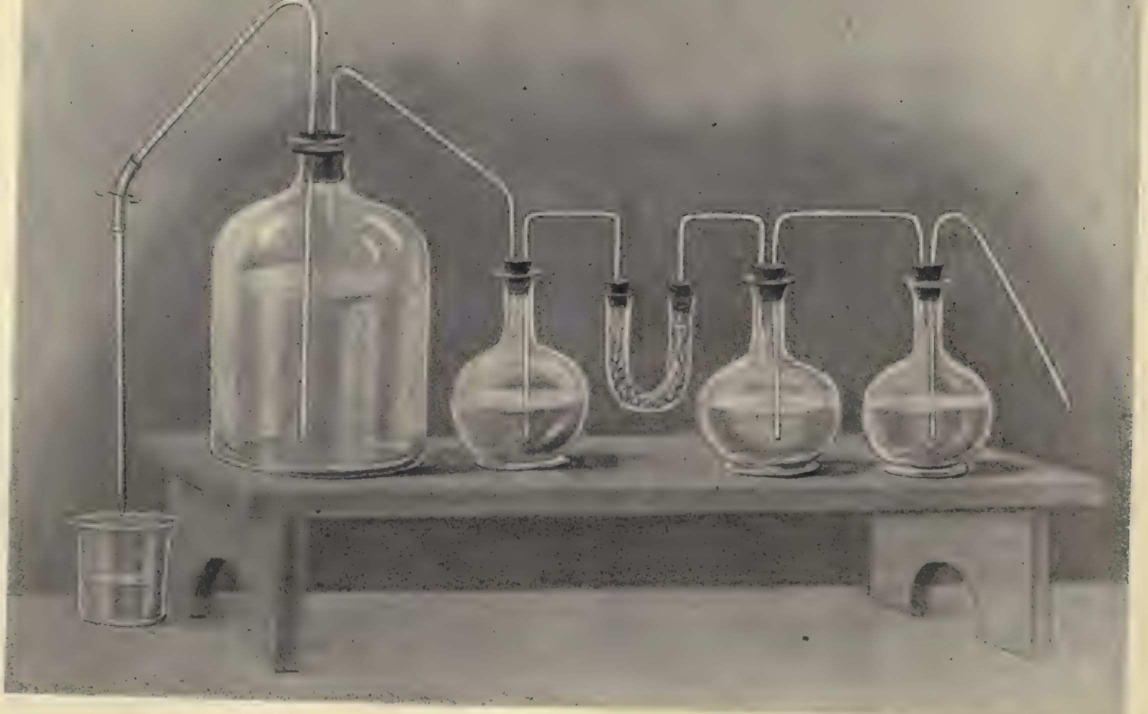

FIG. 9. By means of the aspirator a continuous current of air is kept up from right to left, the peas in the U-tube being thus supplied with oxygen. The contents of the various vessels, beginning from the bottle on the left, are water, lime-water, peas, lime-water, strong caustic solution.

the bottle to induce a current of air is known as an aspirator. If the bottle is large it will continue acting for a considerable time. When empty it may be refilled. By use of the clip the rate of outflow can be regulated. If everything has been properly fitted together, the air will be seen bubbling through the liquid in all the flasks. In a short time the lime-water in flask 3 should show signs of milkiness, proving the presence of carbon dioxide.

1. What is the use of the potash solution in flask 1?

2. What is the use of the lime-water in flask 2?

3. In what respect is the U-tube better in this experiment than a bottle or flask?

4. What is the object of having some of the tubes in the flasks reaching to the bottom?

5. What would happen if the short arms were also extended to the bottom of the flask?

Although the above experiment looks more elaborate than the preceding ones, there is really no difficulty in setting it up. It is, however, essential that all stoppers fit well, and also that the tubes fit tightly into the holes of the stoppers. Any slackness will cause leakage. Should a U-tube and the flasks not be available, bottles may be substituted, with this precaution, that the bottle holding the peas ought to have one of the tubes reaching to the bottom.

This experiment certainly proves that carbon dioxide is formed in germination. Does it also prove that some or all of the oxygen of the air that is drawn in and made to pass over the peas is used up in the process of forming the new gas? Before rashly answering this question in the affirmative, let us set up the following experiment.

EXPERIMENT No. 22 (Fig. 10).

Apparatus and Material.

Soaked peas.
Test-tube.
Mercury.
Metal stand with clamp.
Mounted needle.
Caustic solution.
Pipette.
Small trough (stoneware or glass).

Fill the test-tube with mercury to the brim. Press a piece of india-rubber on it, and, holding this firmly in position, invert the tube in the trough, already partly filled with some of the same liquid. Having fixed the tube in position, skin four or five soaked peas. Lift them one by one with the needle, press them down in the mercury and get them under the mouth of the test-tube. Pull the needle away and release the pea, which will immediately rise to the top. When all the peas have been thus placed in the tube, finally fix it and set aside the whole experiment in the dark for a day or two.

Several precautions must be taken in making the above arrangements. In the first place everything should be on a tray, so that if any mercury is spilt it may be caught. Secondly, pour in the mercury very carefully into the tube, holding the latter in a slanting position so as to reduce the impact of the heavy metal on the bottom of the tube, which may easily be broken. The tube must also be inverted with great care, otherwise some air will appear at the top of the tube, and it is desirable that not even the smallest quantity of it should be admitted.

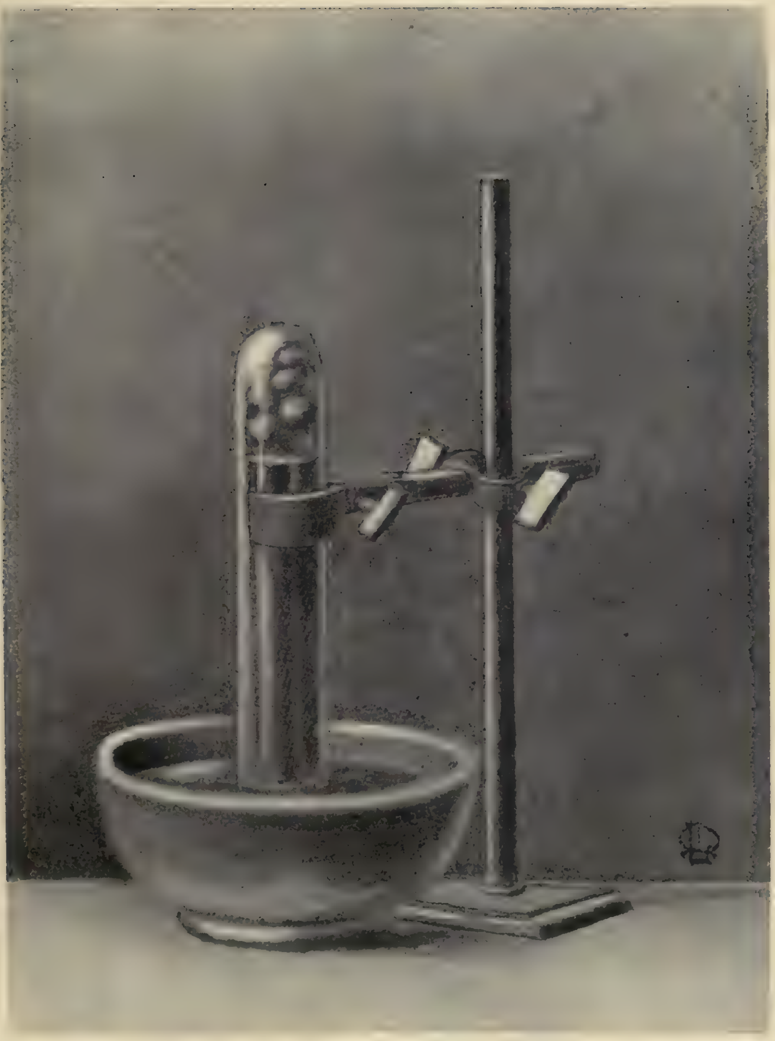

FIG. 10. Respiration in the absence of atmospheric oxygen.

1. Why should the peas be skinned?

2. Why do you think the peas will not germinate when completely surrounded by mercury?

3. Why in particular do you think it will be impossible for them to produce carbon dioxide?

4. What prevents the mercury falling down by its own weight when the tube is inverted in the trough?

5. What objection would there be to using water in this experiment instead of mercury?

6. Suggest any other liquid that might perhaps prove satisfactory.

Contrary to natural expectation, at the end of a couple of days the peas will be found occupying a clear space at the top of the tube instead of being almost hidden in the mercury as they were at the outset. Clearly some gas has been formed and this has forced the mercury down. It is possible to prove what gas this is without removing it from the tube. Take a small quantity of strong solution of caustic potash in a pipette. Get the end of the pipette under the test-tube and squeeze out some of the solution. It immediately rises to the top, and if it rests on the mercury to a depth of $\frac{1}{8}$ or $\frac{1}{4}$ inch that will be sufficient. Now watch the mercury. It almost immediately begins to move up. The gas that exerted pressure on it is being absorbed. In a short time the mercury has reoccupied the vacated space except for the small portion occupied by the caustic itself. There is no doubt the gas thus absorbed is carbon dioxide. The peas, it is surprising to find, have given out their usual breath even in the absence of air. At first this seems out of the question, but it undoubtedly has occurred. How can we account for the manufacture of carbon dioxide without the air which supplies the oxygen? The only possible answer to this is that the peas had a special supply of the necessary gas within themselves. This, indeed, is the true explanation. Breathing carried on under these conditions is known as intra-molecular respiration.

Turn again to Experiment 21. It is now evident that it would be unsafe to conclude that the oxygen of the air entered into the case at all. For all we know, intra-molecular respiration may have been going on—that is, the oxygen which must be supplied in some way before carbon dioxide is formed may have come from the peas themselves. In order to show that plants actually do use up atmospheric oxygen, we turn to still another respiration experiment.

EXPERIMENT NO. 23.

Apparatus and Material.

Soaked peas.
Test-tube.
Caustic potash solution.
Filter flask, fitted with solid rubber stopper.
Long glass tube of 2 or 3 mm. bore, with a short arm (1 in.) at one end.
Piece of rubber to connect the glass tube with the side connexion of the filter flask.
Small bowl of mercury.
Metal stand and clamp.

Put the peas in the flask to the depth of an inch or so, introduce a tube containing the strong caustic solution, and close the flask tightly with rubber stopper. The long glass tube (which should have previously been attached) is kept in position by the metal stand and clamp and is allowed to slope very slightly towards the reservoir of mercury, into which it dips by its bent arm Attach a scale and record the rate of the progress of the mercury along the tube. It is evident that some gas is being used up.

1. Show that this must be oxygen.

2. Suppose that we begin with the mercury half-way along the tube, and suppose that no atmospheric oxygen were used up, how would the formation of carbon dioxide affect the movement of the mercury?

3. What would happen if the conditions were as in 2, but without the caustic solution?

4. How would the working of the experiment be interfered with if the atmospheric temperature rose during its progress?

Plants therefore depend upon the atmosphere for a supply of oxygen, just like a lighted candle or a living animal.

We ought also to note that (leaving intra-molecular respiration out of account) if we know in any particular case the exact volume of carbon dioxide produced, we know that exactly the same volume of oxygen has been used up, the atmosphere being poorer in oxygen by just that amount.

This seems to make matters worse than ever for all things that breathe. Not only is the poisonous gas discharged into the atmosphere, but the oxygen is removed. How is breathing to go on? By what process is the air kept pure? How is the poisonous carbon dioxide taken away? How does the air receive further supplies of the life-supporting gas?

Note.

It has been shown that plants and animals resemble a lighted candle or a coal fire in producing carbon dioxide and generating heat. Plants and animals are alive and the fire is not. Yet the similarity in essential points is complete and the resemblance of a fire to animate creation is suggested (perhaps unintentionally) by the expression 'live coals'. Note further that plants, animals, and burning coals all give rise to energy. In all three there is also waste. There are, however, points of difference.

1. The fire does not feed itself—it needs to be fed.
2. It does not pass through a terminable series of stages from youth to old age, each exhibiting well-marked features.
3. It does not reproduce its kind.
4. It has no organs and no distinctive shape.

CHAPTER IV

LIGHT AND FOOD

THE relations between light and food may not seem to be very close, at any rate from the human point of view. The fact that man and animals generally seem to feed mostly during the day may appear only an accidental arrangement. But consider something more important—the food-supply. Suppose the light of the sun were to be withdrawn for some weeks preceding harvest, the grain crops would not be worth reaping and there would be a famine in the land. Even though everything else remained as usual, there would be no results without sun. It is a case of no light, no bread. Under the suggested conditions, fruits as well as cereal crops would be doomed to failure. Would plants generally starve? Would trees and shrubs, would grass and other ordinary wayside herbs be without the means of keeping themselves alive? That would depend upon whether plants really feed at all, and, if they do, upon what their food consists of. The former question can very easily be settled in a general way. Plants have already been compared to a burning candle. Both they and it give off carbon dioxide, but in doing so the candle wastes away and the plant, under apparently similar conditions, goes on increasing in size, and, what is still more to the point, in weight. This can only be accounted for by supposing that from an external source it obtains something which it builds up into its own structure. In other words, it feeds, and we must now find out on what. We may postulate at the outset that, whatever it feeds on, the materials composing that food must be derived from (or consist of) the soil, or the air, or water that has fallen as rain, for these three sum up the

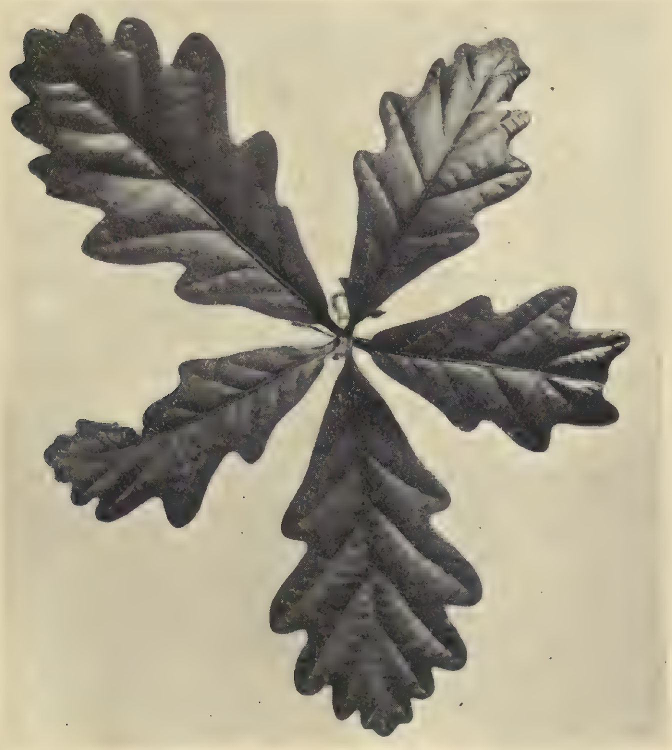

FIG. 11. Seedling oak (photographed from above) showing how the leaves spread in five directions. In this way all of them are in full light, none shading another.

material environment of the plant. Anything not coming from the outside would not be an addition to the substance of the plant, would not be food. What part of the environment, then, does the plant utilize? The natural answer is the soil, but the idea that the plant feeds on the soil needs a little modification. We must remember that, whatever plants feed on, they differ from animals in taking in nothing that is solid. Before, therefore, the soil is possible as plant food, it must be in a liquid condition. It must be dissolved by the rain. Only a very small proportion of any given quantity of soil is soluble in ordinary water, and a plant has its chance of feeding on the soil limited to this. Is it, then, from the air, which is gaseous, or from the water, which is liquid, or from the soil, which is solid, that the indispensable nourishment is drawn? Various questions present themselves.

1. Is the plant continually feeding as it is continually breathing?
2. How and where does the food enter the body of the plant?
3. Does the food vary with the kind of plant?
4. Of what does the food consist?

Before proceeding to investigate experimentally, we might tentatively form some answer to the last question.

(1) It would not be surprising if plants which are alive like animals and which grow like them should require similar food. Now human food, for example, is well known to consist largely of *carbohydrates*. A carbohydrate may be defined as a compound body in which carbon, hydrogen, and oxygen are all represented, and in which the two last-named elements occur in the

same relative proportions as in water—that is, as two to one. The formula of starch, for example, which is one of the commonest carbohydrates, is $C_6H_{10}O_5$. These symbols give the composition of the compound and show it to contain six atoms of carbon, ten of hydrogen, and five of oxygen. Another very important class of foods consists of the *proteins*. These contain, among other elements, a proportion of nitrogen.

(2) As is well known, animals lay up stores of food for themselves and their offspring. Plants do the same, and as the materials accumulated by them in this way are useful as human food, we are well acquainted with their character and composition. Take, for example, the wheat grain. Besides the minute plant which each grain contains, there is a relatively large amount of nutritive material upon which the germ will feed when growth begins. This material by the process of milling is made to yield flour, and from it ordinary white bread is baked. A very simple experiment, consisting of the application of the iodine test, shows that in flour (and therefore in bread) there is a large proportion of starch. What is good for us is the best the plant can provide for its own progeny. The embryonic plant to some extent at least finds nourishment in the same compound as we do.

(3) Consider further the purpose of food and we shall in another way arrive at the same conclusion as the above facts point to. Recall the case of the fire. It, too, requires to be fed. As it burns it wastes. Carbon dioxide is being formed by a union of the oxygen of the air (of which there is generally an abundant supply) with the carbon contained in the coal on the fire. This is a limited quantity, and when it is used up the fire goes out. If more coal is put on in time, the fire continues to

burn while the new supply of carbon lasts. Other substances, such as wood or peat, serve instead of coal.

1. Why do pieces of paper or sticks take fire more easily than coals?

2. Why does blowing on a fire make it burn better?

3. Explain why water thrown on a fire puts it out.

4. If ash will not burn at all, what conclusion do you form about it?

It is just the same with plants and animals. By their breathing the body is robbed of carbon, and if the flame of life is not to be allowed to go out, the wastage must be balanced by new supplies. These form the food of the plant or the animal. When we take starch-containing foods we are repairing the waste of carbon, and if plants feed on carbohydrates they are doing the same. If they do not use such compounds, they must certainly feed on something else containing carbon, otherwise they could not possibly go on breathing. Let us summarize the foregoing considerations.

1. Animals feed on carbohydrates. Perhaps plants do the same.
2. The stores of food in plants contain largely these same substances.
3. As plants really do repair the wastage caused by breathing, it is clear that their food must partly at least consist of substances containing carbon.

Everything considered, it seems quite likely that carbohydrates may form the food or part of the food of plants. If they do, we are at once faced with the question, Where do they get them? For the sake of simplicity, let us suppose starch to be the particular carbohydrate they feed upon. Where does the starch come from? It will be no answer to this query to say it comes from the food store. That only alters the question. How does the starch come to be there? The matter seems all the more difficult when we consider that neither in the air, nor in the water that moistens the soil, nor in the soil itself is any starch to be found. We can only conclude that it is formed in the plant itself. If only a very small quantity were found, we might imagine it had inherited it from a parent plant, but this would not explain matters without new supplies sometimes. Again, look how the amount inside a plant gets greatly increased. Put a small potato in the ground in the spring. In autumn we find that the plant developed from this has produced perhaps ten new tubers, which may contain ten times as much starch as the original one. Clearly the plant has some means of manufacturing its own supplies. Is the starch, then, produced where it is found in such quantity—that is, in the case of the potato, in the tuber? Is it found in other parts as well? Try a leaf.

EXPERIMENT NO. 24.

Apparatus and Material.

A green leaf (geranium, clover, bean).
Methylated spirit.
Beakers.
Iodine solution.[1]

Pull the leaf on a bright day after some hours of sunshine. It should not be too old or too young. To soften it, boil in water a few minutes. Transfer to methylated spirit in a beaker. This is to remove the green colouring matter (the chlorophyll) which in some kinds of leaf comes out quickly if the spirit is heated or gently boiled. The colour may also be extracted by allowing the leaf to lie in cold spirit for a day or two. When all trace of green has disappeared, remove the leaf from the spirit. It is now brittle, but if it is dipped in boiling water the stiffness immediately disappears and it is ready to be treated with the iodine solution. For this purpose lay the leaf (taking care not to tear it) on a plate or in a crystallizing dish, and pour over it a solution of iodine, not too strong. If starch is present the leaf will change to a colour in which blue or purple may be detected. If there is much starch the leaf may appear almost black. Having proved that starch may occur in the leaf, we next ask under what conditions it occurs? If starch is the food of plants and if plants grown in the dark look starved, as they do, we may conclude that starch cannot be formed without light. A simple experiment will show if this is so.

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[1] See Appendix E: Iodine.

EXPERIMENT NO. 25.

Apparatus and Material.

A healthy pot-plant of geranium.
Beakers.
Iodine solution.
Methylated spirit.

At the close of a sunny day remove one leaf, immerse in boiling water for a few minutes, and then leave to soak in a beaker containing methylated spirit. The plant itself is to be placed in a dark cupboard for two or perhaps three days. Then take it out, remove one leaf and treat it like the first. Leave the plant in sunlight for some hours and remove a third leaf. After all the leaves have had their colour extracted, test as above for starch. By cutting their stalks of different lengths, the leaves may easily be distinguished from one another without being kept apart. It will likely be found that the first and third leaves contain starch while the second has none.

1. How can you prove that the life of the plant does not come to a standstill immediately it is put in the dark?
2. What may be learned from the third leaf that we did not know from the first?

Light evidently is a *sine qua non* in the formation of starch, but this is not the whole truth. Where are the raw materials obtained? The carbon for one thing? Carbon, of course, occurs in the air combined with oxygen in the form of carbon dioxide, but it is present only to the extent of about three parts in 10,000 of air. It does not seem likely that this source could suffice for the large quantities of starch made by the vegetation of the world, but we must not decide this point one way or the other without a decisive experiment.

EXPERIMENT No. 26 (Fig. 12).

Apparatus and Material.

Pot-plant with long stem, and with leaves near the foot as well as at the top.
Bell-jar.
Crystallizing-dish.
Circular bath, large enough to go round the bell-jar.
Glass tubes.
Caustic potash (or caustic soda) solution.
Soda lime.
Plasticine.

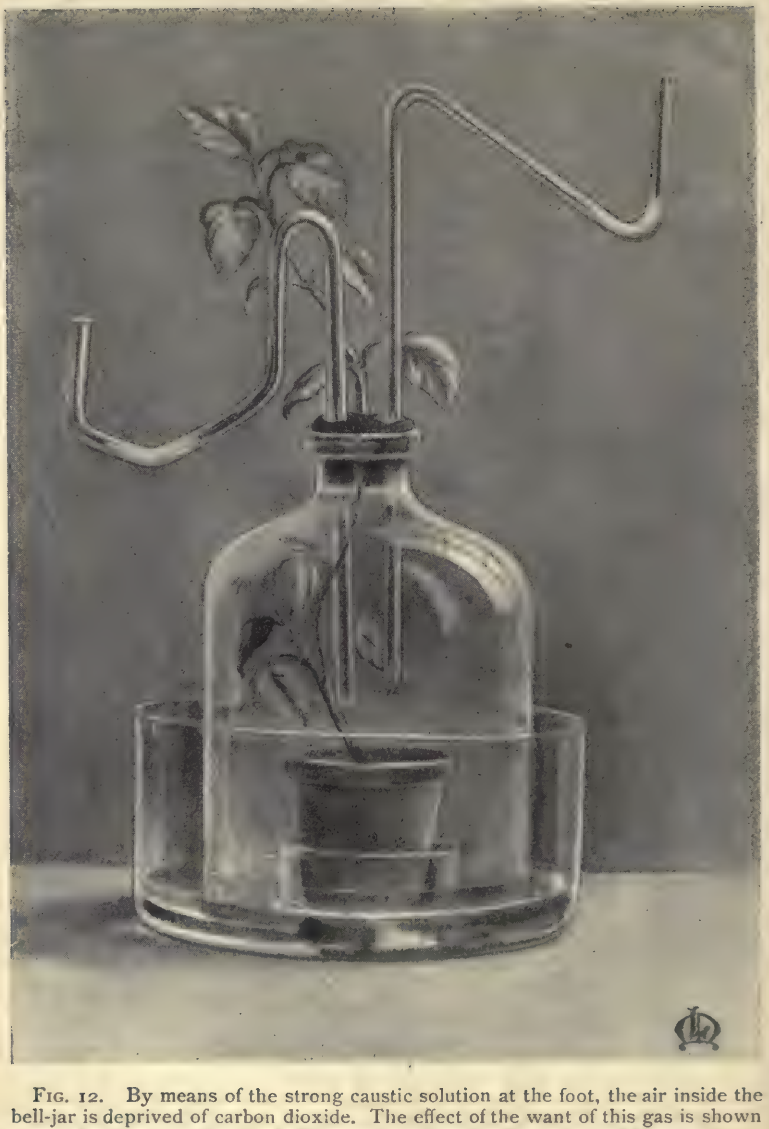

FIG. 12. By means of the strong caustic solution at the foot, the air inside the bell-jar is deprived of carbon dioxide. The effect of the want of this gas is shown when a leaf from outside the bell-jar and one from inside are tested for starch.

After the plant (which may be a geranium or a fuchsia) has been in a dark cupboard for two or three days, arrange as follows. Place the crystallizing-dish in the middle of the glass bath and set the flower-pot in it. Now put the bell-jar over the plant, but allow the stem with the upper leaves to protrude from the tubulus, some of the lower leaves being inside the bell-jar. Two bent glass tubes are now arranged as shown in the diagram and fixed in position with plasticine. Small pieces of soda lime are run down to the bend of each of the tubes and caustic solution is poured into the glass bath to the depth of about half an inch. The whole is now placed in full sunlight and left there for one day or for two if more convenient. Then pull a leaf from the part of the plant outside the bell-jar and another from the plant inside and test them for starch. What conclusions would you draw—

1. If both leaves showed the presence of starch?
2. If neither contained starch?
3. If the one from the outside of the jar contained starch and the other did not?
4. If the result were the opposite of this?

Two conditions necessary for the formation of starch in the leaf have now been demonstrated. A simple experiment reveals a third.

EXPERIMENT NO. 27.

Apparatus and Material.

Geranium plant with variegated leaves.
Methylated spirit.
Iodine solution.

After the plant has been exposed to bright sunlight for several hours select two or three leaves. Make drawings and show by shading or otherwise which portions of the surface are white and which are green. Then test for starch.

1. In what portions of the leaf is starch not found?
2. What conclusion is warranted by the result?

It might be well to include in the experiment variegated leaves of other kinds of plants. The conclusion formed would then be more generally applicable.

We have seen that the leaves do not form starch in an atmosphere devoid of carbon dioxide. This gas is indeed part of the raw material, and without it, of course, it is impossible to have the finished product, but under favourable circumstances the green leaf seems to be always making starch. That, however, is not the whole of the story, as will presently be seen.

EXPERIMENT NO. 28.

Apparatus and Material.

Leaves of some vigorously-growing plant.
Battery-jars or large wide-mouthed bottles.
Apparatus for making carbon dioxide (see p. 28).
Corks or glass circles to close the mouths of the jars or bottles.
Test-tube.
Plates.

Fill one of the jars with water. Invert it with the mouth under water and run some carbon dioxide into it. Close the mouth and shake so that the gas gets well mixed with and absorbed by the water. Open under water and introduce a number of leaves or leaf-bearing shoots. Still keeping the jar inverted, put a plate below the mouth and then set the apparatus in the sunlight.

The surface of the leaves will soon be covered with minute bubbles, and if the jar is shaken a little or tapped, they rise and collect at the top. As the quantity of gas got this way in the course of the hours of sunlight may be small, it is better to set up several jars of leaves and then (under water) run the total of gas produced into a single test-tube. When this is full cover the mouth with the thumb or a piece of rubber until you are ready to introduce a glowing splinter of wood. This ought to burst into flame, showing that the gas is not the gas that was mixed with the water at the beginning of the experiment, but oxygen instead.

We have now come across two operations that are carried on only in the light—the formation of starch and the liberation of oxygen. As both processes are the result of the activity of the leaf, we might guess that there is some connexion between them, especially as they both go on during sunlight and as they both stop with dark. Where has the oxygen come from? Why should the leaf have it to spare whenever it is manufacturing a substance which cannot be formed without this very gas? We should naturally expect the leaf to be taking oxygen in and not to be giving it off. But the matter is easily explained when we consider the raw materials at the disposal of the leaf. Starch is composed of carbon, hydrogen, and oxygen. These three elements are indispensable, but the leaf cannot obtain them separately, or in the proportions required. Oxygen in a free state could be got, but carbon and hydrogen can be obtained only by the plant taking in the compounds of which they respectively form parts, namely, carbon dioxide (CO_2) and water (H_2O). So, when carbon dioxide from the air and water from the root meet in the cells of the leaf, and under the influence of light are being built up into starch, oxygen is present in greater proportion than is required for the new compound. It is the excess of oxygen that escapes in the form of bubbles into the water if the plant is submerged, or, otherwise, directly into the air.

To the process of starch-formation in the leaf is given the name of *photo-synthesis*, and some of the chief facts connected with it are these:

1. Starch is formed only in green parts of plants.
2. Sunlight is necessary.
3. The raw materials are carbon dioxide from the atmosphere and water from the soil.
4. While starch is being formed oxygen escapes into the air.

The following points should be noted:

1. It is correct to say that the plant feeds on air and water as well as on some portion of the soil.

2. Only a small percentage of the water taken in by a plant is diverted to starch-production. The rest simply passes through, as will be more fully explained in the next chapter.

3. Most remarkable is the fact that carbon dioxide, present in the atmosphere only to the extent of about three parts in 10,000, is so indispensable as it is. Without this small percentage of the gas green plants could not exist.

4. The facts suggest an important difference between plants and animals. The latter cannot live without other living things to feed on. The former can live on inorganic matter. From this they manufacture their own food. They first make starch or other compound and then feed on it.

We see now the importance of the facts illustrated by Experiment No. 28, which shows the liberation of oxygen. Plants, animals, and fires of all kinds are polluting the air with carbon dioxide and at the same time using up large quantities of oxygen. The realms of air are wide and the supplies of oxygen seem endless, but if plants, animals, and fires went on consuming it and nothing were done to replace it, there would assuredly come a time when the oxygen would be so reduced in amount and the carbon dioxide so increased that animal life, as we now understand it, would be quite impossible. Such a catastrophe is warded off by the action of plants themselves. They give off oxygen while starch is being made. To vegetation alone is due the preservation of the balance which the breathing of both plants and animals and all kinds of ordinary burning tend to disturb. By their action the relative quantities of the gases of the atmosphere are kept approximately constant. It is impossible to exaggerate the far-reaching consequence of this beneficial activity—nor its magnitude. Every green plant that grows adds its own quota of pure oxygen to the volume of this gas that the vegetation of the world is daily during the hours of sunlight restoring to the ocean of air. The humblest herb, as well as the biggest tree, acts in the same way. If from a few leaves exposed to the sun in a jar for some hours we can fill a test-tube with the indispensable gas, what a quantity must be given off by a large tree with a million leaves or more in the four or five months of summer! And it is not a solitary tree, but the forests and pastures of the world that are to be taken into account. It is easy to see that the total volume of oxygen that is set free by the vegetation of the globe in the course of a year must be vast indeed.

CHAPTER V

THE PLANT AND WATER

EVERY one who has a garden, or a conservatory, or even a window-box, knows how very marked is the effect of water[1] upon plants. When in need of it they droop, but if watered before the process of getting dried up has gone too far, they recover, get firm again, and look generally refreshed. Leaves and flowers that have been carried in the hand, or left lying on a table till they are limp and formless, undergo an astonishing change if placed with their stalks in water. It is true that in some parts of the world plants seem to get along with a very scanty supply of water, and even in this country there are great differences, certain species being able to stand drought for weeks or even months, while others, if exposed to the same conditions, would be dead in a day. What, let us inquire, is the precise benefit that plants derive from water? This question has already been partly answered, for it has been explained in Chapter IV that water is required by green parts of plants as raw material, along with carbon dioxide from the air, for the building up of starch and similar compounds. Only a fraction, however, of the water taken in goes to the production of food materials like starch. What is the use of the steady stream that passes from the root to the stem and other parts? The withering of cut twigs or flowers can reasonably be put down to the fact that they have lost connexion with the root, and not only to want of water; but pull a plant up root and all, and place it in dry soil, and the result that comes from lack of water alone will very soon be apparent. There are also other ways of giving an idea of the importance of water to the plant.

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[1] See Appendix F: Water.

EXPERIMENT NO. 29.

Apparatus and Material.

Piece of fresh potato or any vegetable tissue.
Drying chamber (Fig. 13).
Chemical balance.[1]

Cut out of the potato a small cube and weigh[2] it. Transfer it to the drying chamber. In five or ten minutes weigh again, and repeat the weighing till all the moisture has gone. The final result is the dry weight of the cube of potato. All the weighings should be recorded, the total decrease noted, and the percentage of water originally present in the piece of potato calculated.

1. How will it be known when all the moisture has left the potato?

2. What is the temperature of the air inside the chamber? Why is a higher temperature both unnecessary and undesirable?

3. What is the use of the two chimneys?

4. Why is the one longer than the other?

5. What happens when a few fine threads of cotton-wool are held (1) at the top of the long chimney, and (2) at the top of the short one?

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[1] See Appendix B: Chemical Balance.

[2] See Appendix C: Weights and Measures.

The following list of weighings (expressed in grammes) shows the sort of result that may be expected:

	PORTION OF ARALIA LEAF.		CUBE OF POTATO		PORTION OF RHUBARB LEAF.	
Time.	*Weight.*	*Decrease.*	*Weight.*	*Decrease.*	*Weight.*	*Decrease.*
9·25	4·9	—	14·53	—	3·57	—
9·35	4·27	·63	14·33	·22	2·85	·72
9·45	4·05	·22	14·15	·18	2·35	·5
9·55	3·54	·51	13·85	·3	1·75	·6
10.5	3·105	·435	13·51	·34	1·33	·42
10.15	2·97	·135	13·215	·295	1·07	·26
10.25	2·785	·185	12·85	·365	·9	·17
10.35	2·65	·135	12·3	·55	·73	·17
11.40	1·81	·84	10·82	1·48	·46	·27
12.30	1·31	·5	9·62	1·2	·46	0
1.20			8·34	1·28	·46	0

1. How do we know that ·46 gramme is the dry weight of the piece of rhubarb leaf?

2. In the case of the potato, would it be correct to say that 8·34 grammes is the dry weight, or that we do not know whether 8·34 grammes was the dry weight or not? Give a reason for choosing the one expression or the other.

3. At several weighings time was lost. Find some of these. How are the next readings affected?

4. Why should the rhubarb dry more quickly than the aralia leaf?

5. From the above dry weight, calculate the percentage of water in the rhubarb leaf.

At another trial the percentage was found to be 90, which means that the rhubarb leaf contains only 10 per cent. of solid matter. The importance of water to a plant like this is at once apparent, especially when we consider that it is almost constantly losing it by evaporation.

Seeds show a contrast to this condition as long as they remain inert, but the first step towards active growth is the taking in of a large supply of water.

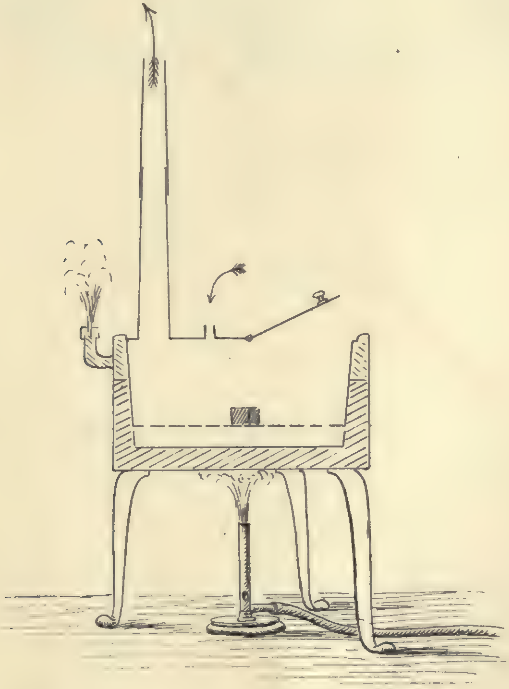

FIG. 13. Drying Chamber.

A bean, which, to begin with, is almost as hard and dry as a stone, after a day's soaking is wet and soft and swollen on account of the water absorbed, and is, of course, much heavier, as can easily be shown by weighing.

EXPERIMENT NO. 30 (Fig. 14).

Apparatus and Material.

Broad bean.
Chemical balance.

Weigh the dry bean and note the weight in milligrammes. Place in water and leave there till the following day. Weigh again. Do so daily, or at intervals of two days, till there is no increase to be recorded. At the second and subsequent weighings all surface moisture must be removed from the bean, which goes on increasing in weight for some time as more and more water is absorbed.

ABSORPTION OF WATER BY BROAD BEANS.

WEIGHTS OF BROAD BEANS BEFORE AND AFTER SOAKING FOR SEVERAL DAYS.

	Dry.	*Soaked.*	*Increase.*	*Percentage.*
No. 1	2580	6050	3470	134
,, 2	2020	5700	3680	182
,, 3	2200	6480	4280	194
,, 4	2140	5820	3680	171
,, 5	1740	4910	3170	182
,, 6	2220	5720	3500	157

The weights are given in milligrammes.

If several results are compared it will possibly be found that individual beans vary considerably in the percentage they add to their weight in a given period. An average amount, as may be seen from the above table, would be between one and two hundred per cent.

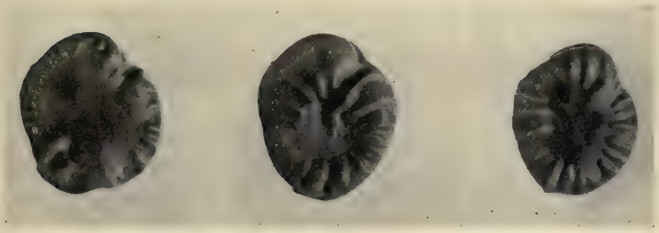

Fig. 14. Beans showing by the furrows and ridges in the skin that water is being absorbed.

Another experiment shows some striking facts about the absorption of water by dry peas.

Experiment No. 31 (Fig. 15).

Apparatus and Material.

Dried peas.
Strong flask.
Stopper with one hole to fit flask.
Long tube fitted firmly into the hole in the stopper.
Paper scale marked in millimetres.

Fill the flask to about one inch below the neck with dried peas. Add water, but not more than is necessary to reach the lower end of the stopper when it is put in firmly. The stopper, with the tube and scale attached, should be ready and ought to be put in place as soon as the water has been added to the peas. Readings are to be taken at intervals. Note that the action begins instantaneously.

1. Does the water come down the tube at the same rate as it goes up?

2. Divide the rise into three equal lengths and calculate the average rate in each of the divisions.

3. Plot a graph from the readings. In making a graph

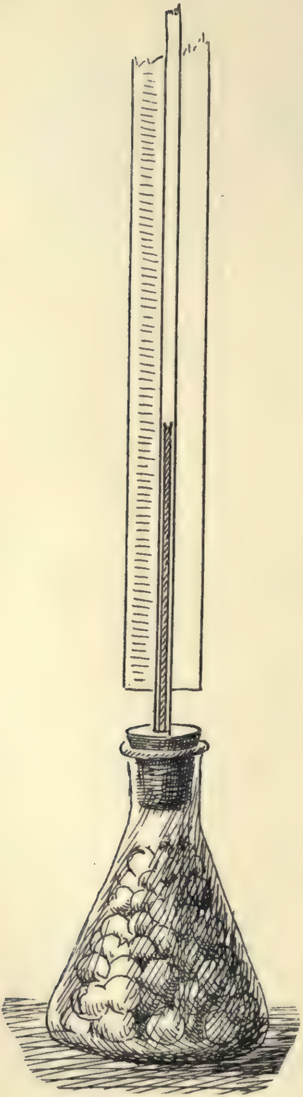

FIG. 15.
Absorption of water by peas.

it is not necessary to mark all the readings. Every fifth one or every tenth might be taken.

4. Find some explanation of the rise of the water.

5. What difference is there between the character of the rise and that of the fall?

With reference to No. 4 one would perhaps suggest that the rise is just what might be expected. But when the peas swell, it is presumably at the expense of the water. Why should a given quantity of peas and water take up more space after some of the water has gone into the peas? It appears that absorption of water with consequent swelling of the peas is not the explanation of the rise.

Wrinkled peas give a good result, but it might be instructive to try this experiment with smooth-skinned ones, as also with other seeds. The rise and fall are much more striking if a tube of fine bore (1 or 2 mm.) is used.

Readings from Experiment 31.

RISE.			FALL.		
Time.	*Height.*	*Increase.*	*Time.*	*Height.*	*Decrease.*
12.49	125		1 15	716	
	160	35		715	1
	197	37		713·5	1·5
	235	38		709	4·5
	275	40		706	3
	310	35		703	3
	350	40		699	4
	387	37		696	3
12.53	423	36	1.19	693·5	2·5
	453	30		689	4·5
	484	31		685	4
	508	24		681	4
	533	25		677	4
	553	20		672·5	4·5
	573	20		667·5	5
	587	14		662	5·5
12.57	602	15		658	4
	615	13		654	4
	628	13		649	5
	640	12		644	5
	648	8		639·5	4·5
	656	8		634	5·5
1 p.m.	665	9		629	5
	673	8		624	5
	679	6		619	5
	684	5		614	5
	690	6		609·5	4·5
	696	6		603·5	6
	700	4		598·5	5
	704	4	1 30	594·5	4
	709	5		588	6·5
	713	4		584	4
	716	3		579	5
	719	3		574	5
	722	3		570	4
	724	2		564	6
	725	1		559·5	4·5
	726	1		555·5	4
	728	2		549	6·5
	728·5	0·5		544	5
	729	0·5		540	4
	729·25	0·25	1·36	534·5	5·5
1.10	729·25	0		529·5	5
				524·5	5

The height of the column of water is given in millimetres and the readings are taken every half-minute.

Having considered in a general way the importance of water to the plant, and more particularly the readiness with which at least the embryo absorbs it, let us turn to the fully developed plant, and inquire—

1. How the water gets into the plant (absorption).
2. How it gets up (ascent of the sap).
3. How it gets out (transpiration).

Absorption. This may be illustrated very simply.

EXPERIMENT NO. 32.

Apparatus and Material.

Leafy shoot.
Straight glass tube two or three feet in length with a bore of three or four millimetres.
Short piece of rubber tubing to join the plant to the glass tube.
Paper scale.
Metal stand.

Cut off the shoot (under water if possible), and, without exposing the cut end to the air, connect it with the tube, the latter being first filled with water. Fix the shoot in an upright position by means of the metal stand, and let the tube lie on the table. Affix scale, and take readings as the water moves.

This experiment shows the plant taking in the water rather rapidly. It may, of course, be objected that this is not a satisfactory experiment because, with the leafy part separated from the root, the conditions are not natural. Let us therefore experiment a second time with a complete plant.

EXPERIMENT NO. 33.

Apparatus and Material.

Small plant with root.
Bottle with side-tube.
Plasticine.

After filling the bottle with water, fix the lower part of the stem in the neck of the bottle with plasticine, and let the roots dip into the water. The plug of plasticine should be worked in with a tapering but blunt piece of wood. Run out by the side-tube any air that may have got in. Fill up the latter if necessary, and cover its mouth with a small loose-fitting cap of paper. If the water goes down in the side-tube the plant must be absorbing by the root.

The absorptive power of the root is mainly due to the presence of innumerable root-hairs. These grow not only on the main root, but also on all its branches. When a plant is pulled up the hairs are not well seen, but in a seedling grown in a damp atmosphere these important organs are very clearly shown.

EXPERIMENT NO. 34 (Fig. 16).

Apparatus and Material.

Mustard seed.
Bottle (preferably flat).

Soak the seeds overnight, and then put a dozen or so of them into the bottle and allow them to adhere (separate, if possible, from each other) to the inside. Cork the bottle and place it in a dark cupboard for a day or two. At the end of this time the root-hairs will most likely have developed. Examine later at intervals and note progress.

1. State approximately the length of the longest hairs.
2. Why are some hairs shorter than others?
3. How are the hairs related to the main root?
4. Where are there no hairs?

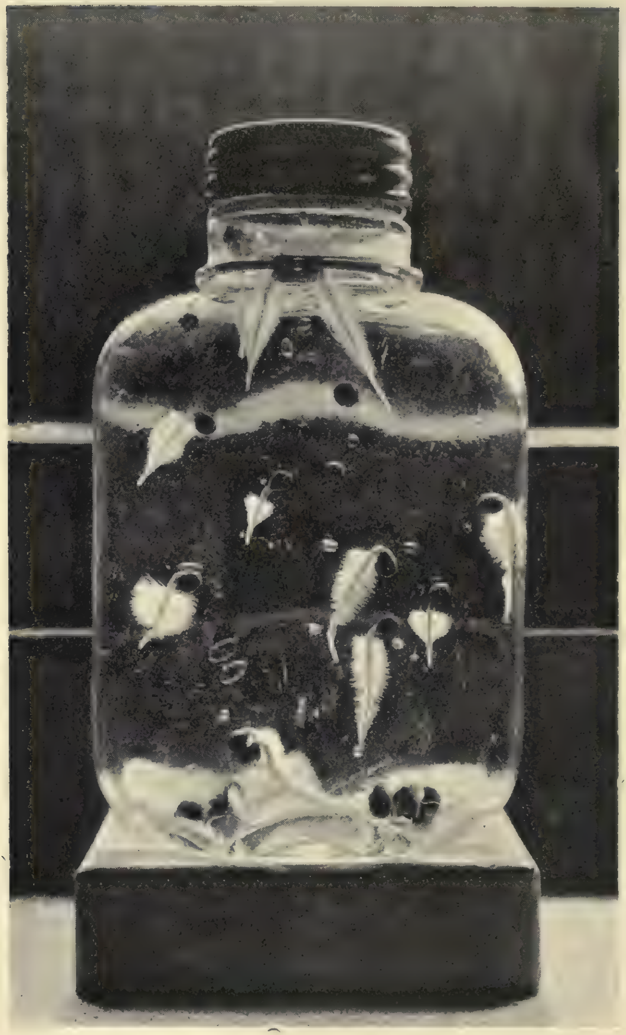

FIG. 16. Mustard seedlings showing root-hairs.

Transpiration. It is clear, therefore, that the root absorbs water and has got a special and very effective equipment for doing so. What happens to the water after it has been absorbed? As a plant grows, it gets heavier. Is the increasing weight due to the retention and accumulation within the plant of the water that is taken in? Some well-known facts are against such a supposition. If fresh leaves are put under a bell-jar, the latter becomes dim owing to a deposit of moisture. This can hardly have come from any other source than the leaves themselves. In dry weather, leaves of growing plants may droop. If we have any doubts that this is due to the loss of moisture, we have only to water the thirsty plants to see them completely restored. The general truth that leaves give off water, or transpire, can, in the case of any particular leaf, be expressed in terms of time, area, and volume.

EXPERIMENT No. 35.

Apparatus and Material.

Leaf with distinct stalk (such as Indian cress).
Chemical balance.
Oil.
Beaker.

Let the stalk of the leaf dip into water in a small beaker. Add just enough oil to form a thin layer on the surface, and see that there are no drops of water on the outside of the beaker or on the inside above the level of the oil. Now balance the beaker on the scale-pan of the balance and leave the beam on the swing. In a short time the scale with the weights sinks, showing that the beaker with the leaf and the water is lighter than it was before. Restore equilibrium by adding a few milligrammes beside the beaker. Go on doing this at equal intervals for some time, and tabulate loss each time.

1. What is the use of the oil?
2. Suggest a modification of the experiment so as to dispense with the oil.
3. In what way would drops of water on the beaker interfere with the experiment?

In order to express the rate of loss of water in terms of a definite area, the number of square inches in the surface of the leaf must be found. This can be done by tracing the outline of the leaf on squared paper.[1] The paper is divided into larger squares measuring an inch along each side, and each larger square is subdivided into 100 smaller squares each of these representing an area of one-hundredth part of a square inch. By counting all the small squares included within the outline of the leaf and dividing by 100, the area of the leaf is found in square inches. In dealing with small squares which are divided by the outline, halves may be reckoned as such, but included portions which are distinctly less than this may be neglected altogether, compensation for these being secured by counting portions distinctly more than half as if they were wholes. After finding the area and the weight of water lost in a given time, it is easy to calculate the loss per unit of surface per unit of time.[2]

Here is a particular case. Eight nasturtium (Indian

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[1] See Appendix C: Estimation of Area.

[2] The pores by which the water escapes may be examined under the microscope. See Appendix B.

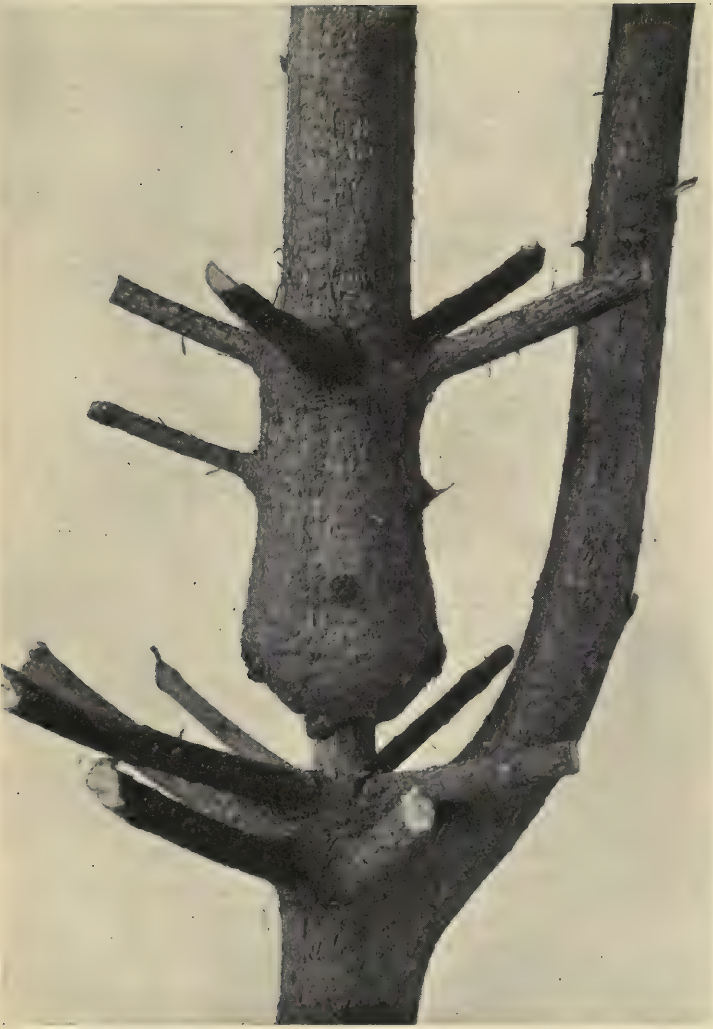

FIG. 17. The constriction in the stem of this plant was caused by the neck of a glass bottle being slipped on to it when young. The result shows that interference with the flow of sap affects the development of the plant.

cress) leaves, with their stalks dipping into water in a beaker, were weighed at 1.30 one day, and next morning at 9.30 the weight had decreased by 13,370 milligrammes. The total area of the leaves amounted to about 80 square inches. By proportion we reach the result that water was given off at the average rate of ·008 grammes (that is ·008 c.c.) per square inch per hour. This experiment was made in November. Two different results cannot properly be compared unless note is also taken of the temperature and humidity of the atmosphere during the experiment.

Ascent of the Sap. Water has been found to go in at the root and go out at the leaves. It remains to account for its passage from the absorbing organs to the transpiring ones. How does it pass up the plant? Bundles of fine tubes run up the stem and out into the leaves, where they form the veins. Even if we can prove that the sap (that is, the water taken in by the root) passes up through these, we have not solved the problem of its ascent. In its upward course the sap is moving against gravity, and could not do so except under the influence of definite forces. In the plant all these forces may act at once, but we must discuss them separately.

(a) *Capillarity.* If a tube of narrow bore is made to stand upright in a dish of water, the liquid rises to a higher level inside the tube than outside, and the narrower the bore the higher will the water rise. This action of the tube on the liquid is known as *capillarity.* As the tubes in vegetable tissue are of extremely fine bore, the rise would be of appreciable extent. Capillarity, however, is not the only force that contributes to a result which, in the case of the highest trees, is the remarkable one of raising water from the ground to a height of

300 feet or more. Let us now consider root-pressure osmotic pressure, and the pull of transpiration.

(b) *Root-pressure.* This is most easily demonstrated in spring, and in some plants it is much more active than in others.

EXPERIMENT NO. 36 (Fig. 18).

Apparatus and Material.

An aralia plant, with a stem about $\frac{1}{4}$ in. to $\frac{1}{2}$ in. in diameter
A T-piece.
Glass tubing.
Strong rubber tubing.
Thin wire.
Paper scales.
Clip.

Cut off under water the upper portion of the plant, leaving the lower portion of stem (five or six inches in length) without branches or leaves. While the plant is still under water (or at least with the cut end submerged), take a T-piece with one end provided with a sleeve of strong rubber closed by a clip, and connect the other end of the T-piece with the cut stem of the plant. The horizontal arm of the T-piece is now connected with a glass tube containing mercury, as shown in the figure. Care must be taken that there is no air between the mercury and the plant, but only water. This can be arranged in the following way.

First put the mercury in the bent U-shaped tube, and thereafter add water to the short bent portion of the arm. Connect the latter with the T-piece (already filled with water), and, by making use of the clip, run off any air that remains. Finally, bring the mercury in the

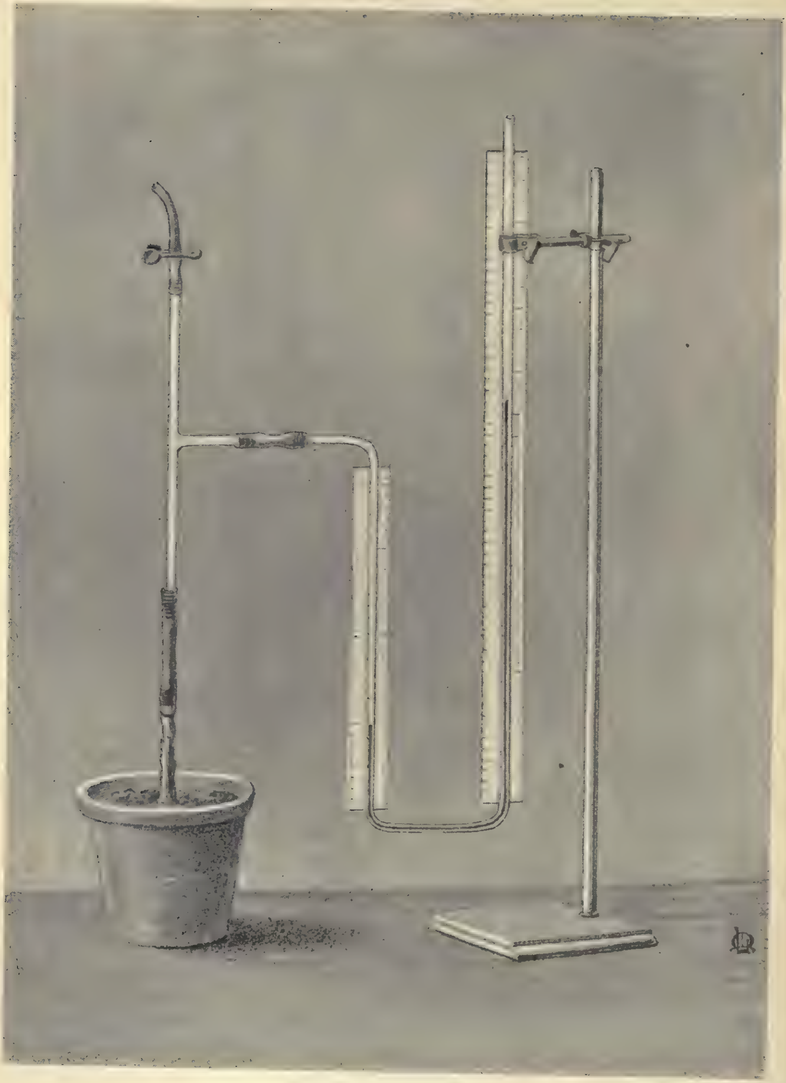

FIG. 18. Root-pressure.

two arms to the same level. Attach a millimetre scale to each arm of the tube and take readings at intervals.

Various precautions should be taken to ensure the working of this experiment. The joinings must be perfect, and, if faulty, may be improved by wire ties, but unless choice is made of a plant with a smooth and firm stem its connexion with the rubber tubing is not likely to be satisfactory. The tube containing the mercury should have a bore of from three to four millimetres. At the beginning of the experiment the plant should be watered. If the mercury falls in the arm next the plant and rises in the other arm, it is clear that water is being forced out of the stem into the tube to which it is attached. If this force were at work in a complete plant, the effect would be to send water right up the plant. This action is known as *root-pressure.*

READINGS FROM ROOT-PRESSURE EXPERIMENT.

		Short Arm.	*Long Arm.*	*Difference.*
Monday,	1.50 p.m.	157	157	0
April 30,	8.10 ,,	152	163	11
Tuesday,	6.15 a m.	148	167	19
	9.30 ,,	141	175	34
	1.45 p m.	138	179	41
	5.20 ,,	132	184	52
	8 ,,	123	191	68
Wednesday,	9.45 a.m.	107	207	100
	1.45 p.m.	102	213	111
	8.20 ,,	92	225	133
Thursday,	6.50 a.m.	83	235	152

Each couple of readings should, of course, theoretically give the same total of millimetres. The divergence from this in some cases may be explained by omission of the fractions of a millimetre and by want of uniformity of bore in the tubes, as well as by inaccuracy of reading. In another trial a difference of 300 millimetres was obtained.

1. If a considerable rise of temperature occurred in the course of the above experiment, how would the readings be affected?

2. How would a fall or a rise of the barometer[1] influence the movement of the mercury in the U-shaped tube?

(c) *Osmotic Pressure.* It is a well-known physical fact that when two liquids of different densities are separated by a permeable membrane, the liquids pass through it at different rates. Various forms of experiment may be used to demonstrate this law. The following is one of the simplest methods of showing it at work.

EXPERIMENT No. 37.

Apparatus and Material.

Three large potatoes.
Strong solution of common salt.
Three crystallizing dishes.

Cut off a small portion of each potato at one end so as to form a flat base for it to stand on. Then, after taking a slice off the top also, make a cylindrical cavity in it to the depth of at least an inch. Set each prepared piece of potato on a separate plate or crystallizing dish, and add liquid as follows. In No. 1 put water in the dish and strong solution of common salt (or sugar) in the potato. In No. 2 reverse this arrangement, putting the salt solution in the dish and the water in the potato. In No. 3, which acts as a second control, put water in both. The solutions, in all cases, may be filled in to the depth of about half an inch. Examine after some hours. In the case of No. I only will the cavity contain more liquid. In it the plain water has passed up into the dense solution much more quickly than the latter has passed down into the water. In this way there is more liquid in the cavity than before. If sufficient time is allowed it will be full to the brim and overflow. If now we have a number of chambers placed one on the top of another, and each separated from its neighbour above and below by a permeable membrane and filled with a solution denser than the one below, there will be an upward movement of liquid which will go on as long as the contents of the chambers retain the relations just indicated.

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[1] See Appendix B: Barometer.

In their earlier stages plants consist of nothing but an aggregation of small chambers, the vegetable cells, each separated from its neighbours by permeable walls. As these bodies have fluid or semi-fluid contents of varying density, it is easily seen that here there is great scope for the exercise of osmotic pressure. As the plant develops, a new structural element appears in the shape of vessels which consist of strings of cells communicating by their ends, and thus forming long tubes; but a proportion of the body of the plant remains in the true cellular condition, and so osmotic movements may still take place throughout the length of the plant.

(d) *The Pull of Transpiration.* The evaporation of water from the leaf-surfaces of a plant is another force that tends to make the sap move up from the root. An illustration of how this works can very easily be arranged.

EXPERIMENT NO. 38 (Fig. 19).

Apparatus and Material.

Porous pot.
One-holed stopper to fit it.
A glass tube about 12 or 15 in. in length, and 4 or 5 mm. in bore.
Basin of mercury.

After the pot has been boiled, fill it with water and fit with stopper and tube. The end of the latter (which must be quite full of water) is placed so that it dips into the bowl of mercury. Fix it in this position with the porous pot at the top. A scale may be attached to the glass tube.

It will be noticed that the surface of the pot is damp, and as the moisture is evaporated more is drawn through the walls of the pot. The water in the pot and the tube gets used up, and the mercury rises to take its place. There is thus a distinct upward pull, and some idea of the strength of it can be got from the height to which the mercury rises. This experiment is not, of course, intended as a proof that a similar pull is exerted in the leaf, but is useful as an illustration of such a force at work. We can, however, see that there is a resemblance between a leaf attached to a stem and the pot at the end of the glass tube. The leaf with its surface from which water passes off into the air is represented by the pot, and just as the water in the glass tube is drawn up towards the latter, so the water in the leaf-stalk and in the stem to which the leaf is attached is drawn towards the inside of the transpiring leaf.

1. What is the use of the mercury?
2. What causes would hasten its rise in the tube?

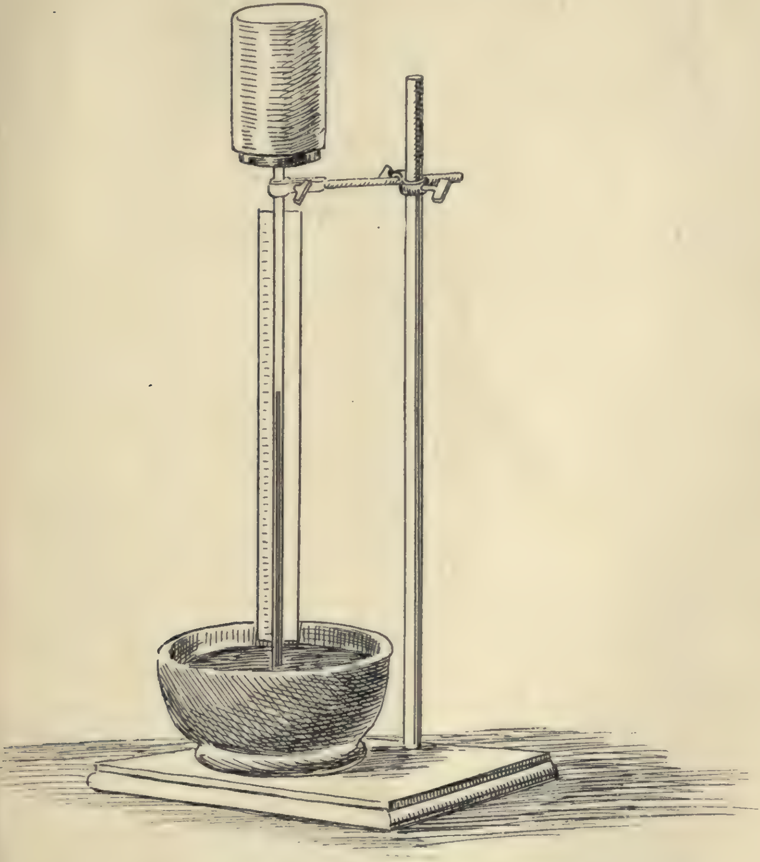

FIG. 19. Effect of transpiration illustrated by evaporation from surface of porous pot.

3. What is the good of boiling the pot before starting the experiment?

4. What would happen if evaporation entirely stopped?

5. How could evaporation be retarded without putting anything in actual contact with the pot?

To show that this pull is really effective in the case of an actual plant, a twig with healthy leaves may be attached to one end of a tube (full of water) which dips at the other end into mercury, just as in the case of the pot.

The ascent of the sap, then, is due, not to a force acting alone, but to the joint agency of capillarity, root-pressure, osmosis, and transpiration, with the remarkable result that water taken from the soil is distributed throughout the plant, however big and however high it may be. There is, in fact, a stream of water, now fast, now slow, directed up from the root through the stem and the branches to every part of every leaf.

It is very necessary to note that the water transpired by the leaf is not in the same state as the water absorbed by the root. The latter is liquid and contains in solution substances derived from the soil. The former escapes from the leaf as a gas,[1] and leaves behind any dissolved matter with which it was charged. This brings us to another important question. What is the good of this continual stream of liquid passing up by day and by night? What is the good of water going into the plant only to escape again? The answer lies in what the water leaves behind it in the cells of the leaf. This material, derived, as we have seen, from the soil, is utilized by the plant in building up the complex compounds which constitute its living substance, and without which it cannot thrive. The water, therefore, is a transport agent, and the greater the volume of it the greater the amount of material brought to the leaf. What is brought is not carried away. The water passes off into the air, but its load remains behind as a permanent addition to the plant. By this means, in course of time, a considerable quantity of matter derived from the soil gets accumulated in the body of the plant.

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[1] See Appendix F: Boiling of Water.

But the use of water to the plant is not limited by this single service. In three other and quite different ways it helps the plant to live.

In the first place, not only does the water taken up by the root act as a supply agent. It is also a supply in itself, for not all the water that comes in passes off. A small proportion is retained and acts as food, or rather as part of the raw material out of which the green leaf manufactures compounds for its own nutriment. This has already been explained in Chapter IV. This particular use of water depends, of course, upon its chemical composition. Two other uses, like its action as a transport agent, are due to its physical properties. Take such a plant as chickweed. Pull it up by the roots and leave it lying on a table or on the ground exposed to the air for some time. A great change comes over it. It looks limp and helpless. It has lost all rigidity. Place the roots in water and in a short time it is restored. The drooping leaves spread out and the stem straightens itself. The water, which cannot by any means be made to stand up itself, enables the plant to do so. This is accomplished by the water filling the separate cells of which the plant is built up and making them turgid, in somewhat the same way as by filling a rubber tyre with air we give it a firm form. Animals are kept in shape by their skeleton, and large plants derive stability from their strong stems and branches. Humble green plants with too little wood in them to give them anything like stiffness are able to keep themselves up by help of the water they contain.

It is curious that this same element which gives to plants a certain firmness or even stiffness is also useful in what seems a contradictory way. It makes them soft. Take again the chickweed or other similar plant, and after it has lost enough water to make it quite limp, allow it to lose all the water that still remains by drying it between blotting-paper or near a fire. It then becomes stiff and brittle, being quite dead. Seeds like the bean, which have only a little water in them, are almost as hard as stones (though not dead like plants or leaves that have lost absolutely all the water they contain), and show no sign of life whatever unless they have the chance of absorbing water. When this reaches the interior of the cells, of which seeds, like plant tissue, generally consist, it brings the living matter they contain into a fluid or semi-fluid condition, and makes vital movements inside the cell possible. It also facilitates the transference of material from one cell to another. Thus the water that makes individual cells soft and their contents fluid gives rigidity to the general framework, which consists of the walls of these same cells.

Taking all the uses of water into account, we see how much this factor in the environment has to do with the life and vigour of the plant, and indeed with the very existence of vegetation on the globe. There is also the other side to the question—the reaction of vegetation on the environment.

In one aspect of physical manifestation the world is one great water-mill. Just as a mill-lade turns the wheel and makes the mill go, so the movement of water on the face of the globe vitally affects the workings of nature as well as human activity. Where rain falls there is a mantle of green covering the bare earth.

Where rain never falls there is an arid desert. Down the hillside runs the stream, supplying power to an extent that is only now being appreciated. Farther down it broadens to a great waterway for the commerce of the nation. And so down to the ocean into which it pours its endless contribution. But this is not the end of the journey, for from the wide waters of the world vapour is continually rising, and this, when distributed by the wind, helps to determine the climate of the world. There is continual movement, and when we think of the rain that feeds the rivers, the rivers that run to the sea, and the sea that rises to the sky, we find that the circle is complete. Cut off the current and the mill-wheel comes to rest, and if rivers became lanes of standing water, and the sea yielded nothing to the air, nature's great machine, by which the earth is made fertile and habitable, would come to a dead stop.

What is the relation of vegetation to this great machine? We can see the rolling of the restless ocean, the steady flow of the broad river, the torrents of rain, and the clouds that cover the sky. These are big things, compared with which vegetation seems just a side-show kept running by the mere fraction of the rainfall which it manages to get hold of. Let us suppose that ·002 gramme is an average weight of water for leaf surfaces to give off per square inch per hour. What a ridiculously small amount this is compared with the volume a large river would pour into the sea in the same time! But it is to be remembered that a tree may have a million leaves and that a forest may have a million trees, and that therefore we must take account of all this, and include, too, every blade of grass. In the case of a large tree the amount of water given off might easily amount to 200 tons in the year. The Mississippi is said to pour into the Gulf of Mexico 21,300,000,000 cubic feet of water annually. That is, in round numbers, 600,000,000 tons. If we admit that one tree can give off 200 tons in a year, then 3,000,000 trees would give off as much water (in the form of vapour) as the Mississippi pours into the Gulf of Mexico. Allow one-tenth of an acre for each tree, and then we could have the requisite number of trees in a country one-fifth to one-seventh the size of the United States. The vegetation of the world is not a side-show at all, but actually part of the mighty machine. Vegetation joins with the stream and the sea in making the air humid and capable of yielding rain. Climate controls vegetation, but it is also true that vegetation helps to control climate.

CHAPTER VI

USES OF THE SOIL

TREES such as the Scotch fir may be found growing where the soil has very little depth, occasionally on what seems almost bare rock. How is this possible if the popular idea that plants feed on the soil is correct? How can trees growing under such circumstances increase in weight when there is so little available solid matter to draw upon? It will not do to say that trees in such positions, although unable to derive much solid material from the soil itself, can add to their weight by absorbing a large amount of water, for let a tree be cut down and dried, the greater proportion of its weight remains. The fact is that a great deal of the substance of a tree (apart from the water it contains) is due to what it extracts not from the soil nor from the water in it, but actually from the air. As already pointed out, carbon dioxide (present in very small quantities in the air) is taken in and the carbon of this gas adds to the dry weight of the plant. This must not be confused with the breathing, which is quite a different matter. After all, however, the popular notion is not wrong; it only requires modification, the fact being that the plant feeds on both air and soil. The following questions may be asked:

(1) How can we prove that the soil is a source of plant food?

(2) What are the other uses of the soil?

With regard to the first question it seems so natural that the plant should absorb nourishment by its root that we are apt to take the fact for granted and to consider proof unnecessary, but the relation of the plant to the soil is not so simple as it looks. Plants and animals breathe in the same way, but they do not feed in the same way. Plants cannot take solid nourishment, and before we can be sure that supplies enter by the root we must show that some at least of the constituents of the soil can dissolve in water.

EXPERIMENT NO. 39.

Apparatus and Material.

Ordinary garden soil.
A glass jar.
Stirring-rod.
Distilled water.
Glass funnel.
Filter-paper.
Piece of clean glass.
Filter flask (or bottle).

Put a handful of the soil into the glass jar and on it pour, say, half a pint of distilled water. Allow the mixture to stand for some hours, stirring it at intervals with the glass rod. After the last stirring, allow the sediment to form, then pour off the watery part and, by help of the filter-paper and glass funnel, filter it into the flask. If it does not come through clear it must be filtered again (perhaps several times) till the brown colour (which is due to extremely small, solid particles that have got through the filter-paper) disappears. Now with the glass rod, which should be thoroughly washed in distilled water, lift a drop from the bottle of distilled water and place it on the piece of glass. Alongside of it place a drop of the filtered liquid. The two drops must not be allowed to unite. Leave them till they dry. This process may be hastened by placing them in a draught or near some source of heat.

1. How do the traces of the drops differ?
2. Account for the difference.
3. What precautions might be taken in addition to those suggested above?
4. How does rain-water differ from spring-water?
5. What conclusion might be drawn from the fact that rain-water is not so good for drinking purposes as spring-water?

This experiment, which shows that the soil is at least partly soluble, by no means proves that the dissolved material actually gets inside the plant. We could imagine the root exercising a selective action, absorbing the pure water and rejecting the dissolved substances. If, on the contrary, the root absorbs them along with the water, they will be found inside the plant, for when the water escapes from the leaves it does so in a state of vapour and takes nothing with it. Let us therefore see whether plant tissues are composed of anything in addition to the water they are known to absorb by the root, and the carbon and oxygen in the form of carbon dioxide which it is known they take in by the leaves.

Chemical Composition. In order to ascertain the effects of its composition a chemical analysis of the plant must be made.

EXPERIMENT NO. 40.

Apparatus and Material.

Dry leaves of any kind.
Crucible.
Wire or glass rod.
Tongs for lifting the crucible.

Crush the leaves and put them into the crucible, which must then be placed in a hollow in a clear fire. Combustion immediately begins and must be allowed to continue till all trace of black matter (which is unburnt carbon) has disappeared. The process is accelerated by stirring. What remains after the burning is complete is known as plant ash. Examine it.

1. What is its colour?
2. How does it feel to the touch?
3. Is it heavier or lighter than water?
4. Is it soluble in cold water?
5. Find out by litmus-paper whether the water you have mixed it with gives an acid or alkaline reaction. If it does, what light does this throw upon the solubility of the ash?

In the preparation of the ash the leaves have been subjected to both drying and burning. The former process removes all the water, the latter most of the carbon. It is evident that these two substances account for most of the bulk of the fresh leaf. The ash, which can be neither evaporated nor burned, is a mere fraction of the dry weight of the leaf, and the dry weight is only a fraction (in some cases less than one-tenth) of the weight of the fresh leaf. Suppose in a particular case the weight of the ash to be 5 per cent. (which would be quite a possible proportion) of the dry weight, then a pound of fresh leaves or other material would yield rather more than one-twelfth of an ounce of ash. To get a pound of the ash we should require to burn 200 lb. weight of leaves. A single leaf weighing 5 grammes (say 75 grains) would on the above basis yield 25 milligrammes (less than half a grain) of ash. More than this, the ash contains many compounds, and so the proportion of any one of these ingredients becomes more insignificant still. It would, however, be a great mistake to estimate the value of any particular substance by the small amount of it present in the ash. The presence or absence of a few grains of certain chemical compounds settles whether a plant will be healthy and grow or fade and die.

We proceed now to apply chemical tests to see what the ash contains. As a rule, in working through these, only small quantities are necessary, whether of the ash itself or of the solvents and reagents employed. When more of a reagent has to be added it should be done gradually. Special care must be taken with the concentrated acids. A tube containing any of these must not be allowed to boil over, and the mouth of it should be directed away from you.

EXPERIMENT NO. 41.

Apparatus and Material.

A supply of the ash.
Twelve test-tubes in stand.
Filter-paper.
Strong hydrochloric acid.
Strong nitric acid.
Ammonium molybdate.
Barium chloride.
Potassium ferrocyanide.
Potassium thiocyanate.
Platinum wire.

(*a*) Put a small quantity of the dry ash in a test-tube, and pour a little of the hydrochloric acid over it. The effervescence which immediately takes place shows that a gas is being evolved. This is carbon dioxide, and we may infer that its formation is due to the action of the acid on a carbonate in the ash. As already seen in Chapter II, carbon dioxide is readily prepared by adding hydrochloric acid to marble, which is a carbonate of calcium ($CaCO_3$).

(*b*) Over a small quantity of the ash pour about twice its bulk of nitric acid, the whole not to occupy more than the lowest inch of the test-tube. Boil and then add water. Filter, and to a small portion of the filtrate add to excess ammonium molybdate. Heat the solution and a canary-yellow precipitate should appear. This shows the presence of phosphates.

(*c*) Dissolve some of the ash in dilute hydrochloric acid. After diluting with distilled water add a few drops of barium chloride. A white precipitate is formed, showing that the ash contains sulphates.

(*d*) To ash dissolved in dilute hydrochloric acid add a drop of strong nitric acid and bring to the boil. Add water and then divide the diluted solution into two portions. To one portion a few drops of potassium ferrocyanide are added, when the formation of a blue precipitate proves that iron is present. Corroboration of this fact is supplied if a red coloration is obtained when the second portion is treated with potassium thiocyanate.

A Dry Test. Dip the end of a piece of platinum wire into hydrochloric acid and then hold it in the flame of a bunsen burner, to which, if quite clean, it will impart no colour. Repeat the process as often as necessary, and then, by means of the wire, hold some of the ash in the flame. Examine the result through a blue glass. A violet colour indicates the presence of potassium.

These are only a few of the simpler tests that may be applied to the ash, but they are sufficient to give some idea of what it contains and how it can be analysed. All the tests are of a *qualitative* nature and indicate only what kind of substance is present. If we wish to go further and find out how much of each compound or element occurs in a given amount of ash, then we must have recourse to *quantitative* analyses. These are much more difficult, and involve, among other operations, very careful weighing.

In the meantime we have shown that the ash contains carbon, sulphur, phosphorus, iron, and potash. A good many other elements also occur. Note the following important facts:

(1) Plants from all over the world contain for the most part the same substances in their ash.
(2) Different kinds of plants, even though growing close to each other, have not got the same proportion of each ingredient.
(3) When it is stated that a plant contains phosphorus, iron, or potassium, it must not be supposed that these are present as elements. They are all in chemical union with one or more other elements, thus forming compounds.
(4) Even though we detect a particular compound in the ash, we must not assume that it occurred in the plant. New combinations may have been caused by the burning.

We have not yet finished with the former of the two questions regarding the soil, proposed at the beginning of this chapter. Two points still have to be cleared up. In the first place, are these materials to be looked upon as food? It is not enough to find them in the ash. We must show that they were necessary to the health and growth of the living plant. This, however, can be done. In the next chapter an experiment is described by which it may be proved that without nitrogen a plant does not thrive. Nitrogen is therefore a food substance, and so with many, though not all, of the various elements represented in the ash. The case of iron is specially striking. This is present only in minute amounts, yet if a plant is entirely deprived of it, it cannot be healthy, as is seen by the paleness of its leaves, which lack the healthy green colour and are no longer able to manufacture the nutritive compounds which it is one of their chief functions to produce.

Let us pass now to the other point. Assuming that the ingredients of the ash represent what the plant took in as food, we have yet to settle where they were got. It must be from the air, from the rain, or from the soil. Though rain is not quite pure distilled water, there are many necessary substances (such as iron or phosphorus) which it cannot possibly provide. The air is equally incapable of yielding a supply of these. Its composition is known, and it lacks most of the elements that are constantly present in the ash. The only possible source is the soil. It has been already seen that the soil, though chiefly composed of insoluble matter, has also in it various substances which can be dissolved by rain-water. The latter enters the plant by the root-hairs and carries the dissolved material along with it. This comes in in very minute quantities, but in time it accumulates, and when the plant is burned it remains as ash. Thus, although plants do not perhaps feed on the soil in the way generally supposed, there is no doubt that an indispensable portion of their food is actually derived from it.

1. The material taken in by the root is soluble, but the ash is largely insoluble. Suggest any cause to which this may be due.

2. What advantage results from burning the natural vegetation where it grows before taking any land for agricultural purposes?

3. What is the object of manuring the ground?

4. Why should it be necessary or desirable to manure ground on which crops are to be raised when wild plants thrive without it?

5. Some crops require more of one substance, other crops more of another. How does this fact affect agricultural practice?

Before leaving this part of the subject, we might apply a chemical test to the soil itself and see if we can discover in it anything that has already been found in the ash.

EXPERIMENT NO. 42.

Apparatus and Material.

Garden soil.
Porcelain basin, or crucible.
Test-tubes.
Nitric acid.
Ammonium molybdate.
Ammonium hydroxide.

Put the soil in the basin or crucible and burn away the carbonaceous material. Boil what remains in a test-tube with a little strong nitric acid. Add water and filter. Add a little ammonium hydroxide and then ammonium molybdate. A yellow precipitate ought now to appear, showing the presence of phosphates.

So the soil is evidently the source of the phosphates, which by a similar test were proved to occur in the ash. Other tests can be arranged to show that the ash contains no elements that cannot also be found in the soil, which is therefore a reservoir of potash, iron, calcium, phosphorus, and other substances which are required to meet the varied needs of the plant.

We must now turn to the second question proposed at the beginning of this chapter and consider other uses of the soil.

EXPERIMENT NO. 43.

Apparatus and Material.

Soil.
Clay.
Glass jar, or wide-mouthed bottle.

Put some of the soil in the bottle, filling it perhaps three-quarters full. On the top of this put a thin layer of clay, taking care to make it a complete cover for the soil. Fill the rest of the bottle with water. Through this and through the layer of clay push down a pencil and then withdraw it. Bubbles immediately escape, showing that the soil contains air and that it is therefore possible for roots to breathe.

1. How do roots breathe if they grow in water?
2. What natural and what artificial processes help to mix air with the soil?
3. Apart from the above experiment, name some facts from which you might reasonably conclude that soil contains air.

Next consider another use. Although the rain falls on the leaves and wets their surface, it does not enter the plant by them, but through the medium of the soil.

EXPERIMENT NO. 44 (Fig. 20).

Apparatus and Material.

Ordinary soil } both absolutely dry.
Some finer soil }
Two glass funnels.
Two filter flasks.
One measuring-glass.

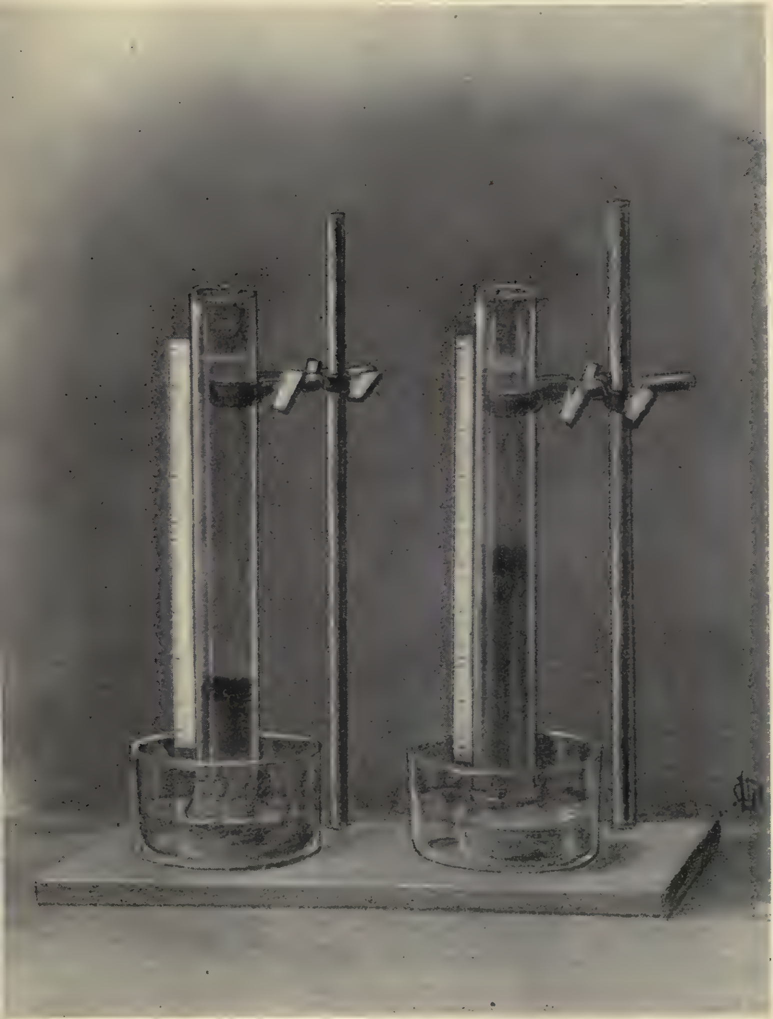

FIG. 20. Arrangement for showing rise of water in different kinds of soil.

By means of sieves it is easy to get sand or other soil of two or more degrees of fineness. Fill one funnel nearly to the top with the finer soil and the other to the same level with the coarser. Use filter flasks to support the funnels, and over the soil in each pour exactly the same amount of water. Some of this will percolate into the flask below. After a little time note in which case the smaller quantity has come through.

If more water is retained by the finer soil, it is not difficult to explain this result. If we take a particle of dry soil and wet it, the water will cling to the surface and form a layer on it. If the particle gets divided into two, new surfaces will be exposed and water will adhere to them also. Thus soil composed of small particles is able to retain much more moisture than soil composed of larger ones. As plants require water not only when it is raining but also during dry weather, which may last for days or even weeks, we can easily see how great benefit they may get from soils that are able to store the indispensable liquid. Soils of this kind do not limit their services to facilitating the passage of water from the surface of the ground to the roots, but are also able to supply it from their reserves during times of drought.

1. Name three ways in which water that falls on the surface of the ground may be removed naturally.

2. What harm comes from soil being too wet?

3. What disadvantage results—
    (*a*) from a soil that is too coarse?
    (*b*) from one that is too fine?

We have not yet exhausted the use of the soil.

Consider next its action in raising water from a lower to a higher level.

EXPERIMENT NO. 45.

Apparatus and Material.

Dry clay.
Dry sand.
Two strong glass tubes, about 18 or 20 in. in length and ¾ or 1 in. in bore.
Muslin.
Thread.
Two crystallizing-dishes.
Two paper scales.
Two metal stands.

Pass the clay and the sand each through a sieve with 100 meshes to the inch. Tie a piece of muslin tightly over one end of each tube. Fill one tube with the prepared clay and the other with the sand. Fix both in an upright position, so that the closed end of each tube may rest on a crystallizing-dish. Attach the scales and then pour a little water round the base. At intervals take readings of the height reached by the water. Continue the experiment for some days.

1. In which tube is the rise the more rapid at first?
2. In which is there the greater rise at the end of 24 hours?
3. Does the rate of rise continue steady or does it fall off or increase after a time?

It is evident in any case that water can be raised to a considerable height. In this way a subterranean supply of water may be available for plants at the surface, and this will be especially useful during excessively dry weather.

Make a complete list of readings and compare it with those given below. A graph may then be plotted which will make clear one of the differences between a clayey and a sandy soil.

READINGS.

Day.	*Hour.*	*Height of water in millimetres.*			
		Clay.	*Sand 1.*	*Sand 2.*	
Wed.	1.6		28	47	×
	1.14		66	112	
	1.23		95	142	
	1.45	35	143	183	
	5.45	83	300	260	×
Thurs.	8.40	146	443	318	×
	10.50	147	454	322	
	1.30	153	—	328	
	6	165	490	335	
Fri.	8.40	187	532	349	×
	11	188	537	352	
	1.30	197	541	354	
	6.40	209	550	358	
Sat.	10.45	235	573	366	×
	6.15	244	581	369	
Sun.	12.40	262	597	375	
Mon.	9.15	280	610	380	
	12.55	286	613	381	
Tues.	10	302	626	385	×
	1.30	307	627	386	
Wed.	12.45	328	638	390	
Thurs.	11	343	649	395	×
Fri.	8.30	361	655	397	
Sat.	10	382	662	401	×
Mon.	11	409	673	406	
Tues	10	423	679	409	×
Wed.	1	442	687	412	×

The above readings show the rise of water in powdered clay and in two qualities of sand. No. 1 quality was passed through a sieve with 100 meshes to the inch. No. 2 quality was about half as fine.

Plot graphs from the readings opposite the crosses.

The fact that some soils are poor is also very important and may be illustrated as follows:

EXPERIMENT NO. 46.

Apparatus and Material.

Beans.
Sand.
Garden soil.
Six flower-pots.

Before setting up the experiment, wash the sand that is going to be used and spread it out till it has sufficiently dried. Fill three pots with this, and the other three with the garden soil. Place a bean in each pot and after some weeks compare the plants. If the plants growing in the sand are smaller than the others, this will show that pure sand makes an unsatisfactory soil.

Summing up the results of the various experiments, we see that soil is of the greatest service to vegetation, supplying it with part of its food and with the air which roots require for breathing.

There is, however, another aspect of the question, for not only does the soil affect the plants that grow in it, but the plants also affect the soil. The soil keeps the plants firm, but in some cases plants do the same to the soil. Grasses with extensive roots are sometimes planted to bind down shifting sands which are otherwise very apt to invade adjacent areas and thereby cause much destruction (Fig. 21).

Then, again, plants help to drain the soil and prevent it from becoming water-logged. This, of course, is for the benefit of the plants themselves, but may also bring benefit to the population of the district by their effect on unhealthy marshes. Trees have actually been planted

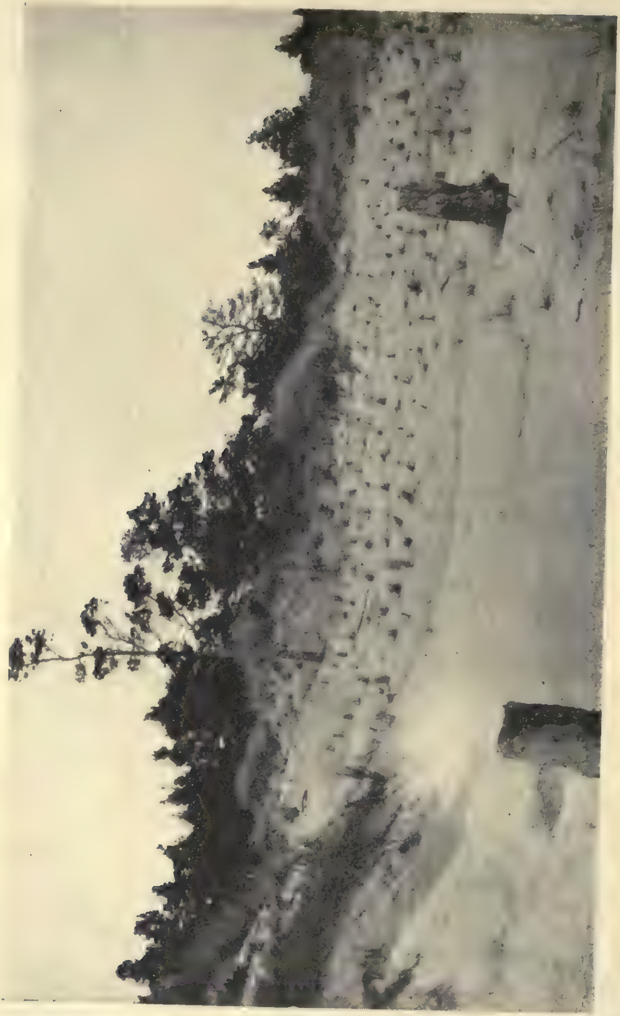

FIG. 21. Portion of a district invaded by sand. Note the grass plants put in to fix it down, and the stumps of two dead trees.

for the set purpose of removing excess of water and thus diminishing disease. In the third place, plants improve the soil by adding new matter to it. When excavations are being made for the foundation of a house, the difference between soil and subsoil is often clearly shown. The darker colour of the former is due to the presence of decayed vegetation. This is known as *humus,* and by it the soil is greatly enriched.

A great deal of the well-being of the world depends upon motion—motion of the air, motion of the water, and motion of the air of the globe. As already pointed out, plants assist in keeping the water of the world on the move. Each plant with its thousands of root-hairs pulls in from the soil a certain amount of water, which, however, is not allowed to rest in the root. It is hurried up the stem to the leaves, from which, by a million pores, it escapes into the ocean of air. From the air it is again discharged as rain which falls on the soil, only to make the circle over again.

The great movements of the air are due directly to the sun, but plants assist in less obvious changes. The leaves are continually taking it in and giving it out. The roots, too, by their breathing and by their removal of water, permit movements of the air underground. If we take into account the cooling effect of transpiration, especially in warm weather, we can see that trees, for example, by changing the temperature of the air within their neighbourhood, must undoubtedly set gentle currents agoing. Even the soil is not allowed to rest, and plants join with the wind and the earth-worm in making it take part in the general circulation of matter.

Vegetation thus seems to command the environment. Tribute is demanded from soil, from water, from air. Not all that goes on is evident to the eye, but we judge of the success of the plant's efforts when we see the result of the whole business in the healthy life and continued enlargement of the plant itself at the expense of the surroundings. When, however, the plant dies, the process is reversed. The environment gets the upper hand and begins to pull to pieces the machine which it previously helped to make efficient. The air that enabled the plant to breathe, now, in the form of wind, makes the dead leaves chase each other in autumn eddies. The water that kept the plant fresh and supplied some of its food now accelerates its decay. The soil, too, claims its share, for hidden in it myriads of micro-organisms are at work and the final result of their activity is the complete disintegration of the plant and the formation of the fertilizing humus.

CHAPTER VII

SOURCES OF NITROGEN

OXYGEN, which composes about one-fifth of the atmosphere, and even carbon dioxide, which is present in insignificant amount, are each of the utmost service to vegetation. Plants like fungi can do without the latter gas, but to all others both it and oxygen are indispensable. We have not yet discussed the relationship of nitrogen [1] to the plant, though it is about four times more abundant in the atmosphere than oxygen. It does not enter into the process of breathing, nor does it form any part of the carbohydrates. Is it of any use at all?

1. Does nitrogen occur in the plant?
2. If it does, is it essential?
3. Is there any possible source other than the air?

In answer to the first question, we must not accept as final the evidence got from the ash. In it certainly there is no trace of nitrogen, but this does not prove that nitrogen was not present in the living plant. The nitrogen may have disappeared in the burning. We must, therefore, test for it in fresh tissue.

EXPERIMENT NO. 47.

Apparatus and Material.

Wheat grains.
Soda lime.
Test-tube.
Litmus (red).

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[1] See Appendix F.

Crush the grains in a mortar, and then heat them in the test-tube along with soda lime. A gas comes off, which may be recognized by its smell and by the red litmus held at the mouth of the test-tube turning blue. The gas is ammonia, a compound of nitrogen and hydrogen. As there is no nitrogen in soda lime, the only possible source for it is the substance of the wheat grains. We have thus proved that nitrogen occurs in plants, but we must not rush to the conclusion that it occurs there in the same state as we find it in the atmosphere—that is, as a gas. The above experiment tells nothing of its condition in the plant. It only demonstrates the fact of its presence. Other tests take us a step farther, and show that nitrogen occurs in the plant in combination with other elements.

EXPERIMENT NO. 48.

Apparatus and Material.

Wheat grains.
Nitric acid.
Caustic soda.
Test-tube.
Glass funnel.
Filter-paper.

Dissolve some of the crushed grains in a small quantity of the acid, add water, and filter. Put in a piece of red litmus-paper, and then very gradually add syrupy solution of caustic soda till the paper turns blue. The solution should now turn dark yellow.

If this happens we infer that the wheat grains contain proteins. These form a class of complex bodies. One of their components is nitrogen, and in this respect they form a contrast to the carbohydrates, which are compounds of carbon, hydrogen, and oxygen only. But before going on to consider whether nitrogen is necessary for the plant, let us take one more well-known test for proteins.

EXPERIMENT NO. 49.

Apparatus and Material.

Wheat grains.
Glacial acetic acid.
Sulphuric acid.
Test-tube.

By gentle heating, dissolve the flour of the wheat grains in glacial acetic acid. Hold the tube at an angle, and very carefully pour a little strong sulphuric acid down the side. The sulphuric acid will settle at the bottom of the test-tube, and at the junction between it and the acetic acid a violet ring should appear. This confirms the presence of proteins.

If these proteins, which occur not only in wheat grains but also in many vegetable tissues, are of nutritive value, the plant will certainly suffer if they are absent. Can it be grown without them? The following water-culture experiment may throw some light on this point.

EXPERIMENT NO. 50 (Figs. 22 and 23).

Apparatus and Material.

Scarlet-runner beans, sprouted in sand.
Two glass jars, about 12 in. in height and 2 in. across the top.
Corks to fit them.
Chemical balance.
Two Winchester bottles.
Potassium nitrate.
Potassium sulphate.
Magnesium sulphate.
Potassium phosphate.
Calcium nitrate.
Calcium chloride.
Distilled water.
Iron perchloride solution.

Make up solutions in the Winchester bottles as follows:

A (normal solution).	B (solution without nitrates).
Potassium nitrate, 1 gramme.	Potassium sulphate, 1 gramme.
Magnesium sulphate, 1 gramme.	Magnesium sulphate, 1 gramme.
Potassium phosphate, 1 gramme.	Potassium phosphate, 1 gramme.
Calcium nitrate, 4 grammes.	Calcium chloride, 4 grammes.
Distilled water, 2 litres.	Distilled water, 2 litres.
Iron perchloride solution, a few drops.	Iron perchloride solution, a few drops.

Fill the jars nearly to the top with water and fix the beans so that their roots, which should be 1 in. or 2 in. in length, dip below the surface. The required support may be got by cutting out a segment of the cork, and if too much is not cut away the bean will be gripped firmly enough to keep it from slipping into the water. Place the two jars where they will get the full benefit of any sunshine that is going, and after the root has developed a little more, gradually replace the water by solution No. 1 in one case and solution No. 2 in the other. Notes may be made of the progress of the seedlings, and special attention should be paid to any differences in development between the two. Allow the plants to go on growing for two months or more. As they increase in height they will require more support. This can be given by making a hole in the cork with a cork-borer and fixing a light cane in it. There is no difficulty in setting up the experiment as above described, but a really successful result cannot be expected without considerable care and continued attention. Even with all precautions failures sometimes occur from causes which may not be obvious.

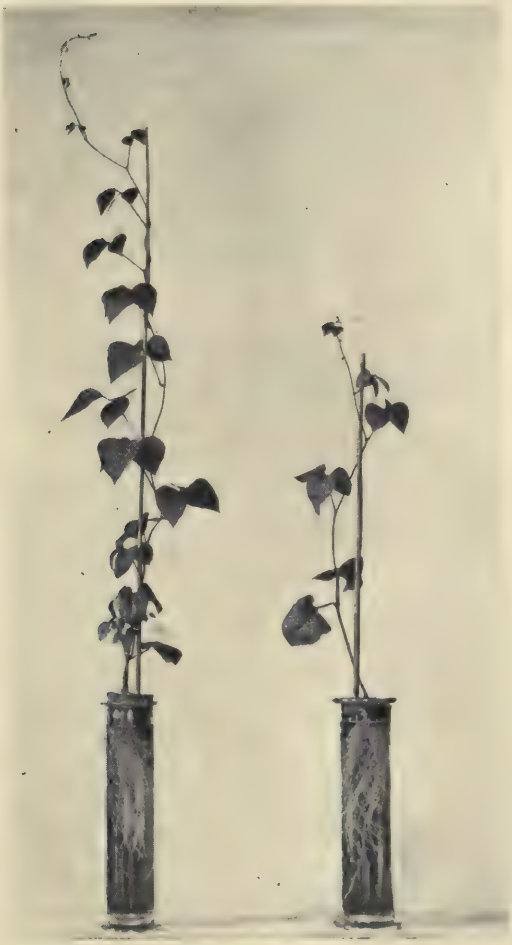

FIG. 22. Water-culture. The plant to the left is growing in a complete solution, while the other is growing in a solution lacking nitrates.

Precautions.

1. To eliminate the element of chance, it is better to set up two or three experiments with solution A and two or three with solution B.
2. Jars and bottles must be thoroughly clean. Wash them first with dilute nitric acid, then with several changes of tap-water, and finally with distilled water.
3. Paper sufficiently opaque to keep out all light must be wrapped round the jars. This will prevent the growth of algae.
4. If a wrapping of white paper is put over the darker paper it will help (on sunny days) to keep down the temperature of the solution, which must not be allowed to become tepid. Test the solutions with litmus-paper. They require to be only slightly acid.
5. Aerate the water periodically with bulb attached to glass tube.

If the experiments are successful, the plants grown in solution A will be healthy and well developed, while those grown in solution B will be much inferior in size and vigour. Even if the result does not come out clearly, the experiment shows the method of water-culture which, by varying the solutions, may be used to determine all the substances which are essential for plant-growth. Water-culture has this advantage over growing a plant in soil, that the extensive development of the roots may be conveniently watched by removing the roll of paper that covers the jar.

1. If nitrogen is necessary, explain why a bean may grow for some time at least in distilled water.

2. Why ought it to grow still better in ordinary tap water?
3. Why should it grow better in tap-water than in rain-water?
4. Why would boiled water not be suitable?
5. In what simple way could boiled water be improved?

Notes on actual Water-culture Experiment.

Capacity of jar about 800 c.c.

The bean was grown for four weeks with water only in the jar, but at the end of that period (April 25) 30 c.c. of solution was added.

May 9. Jar emptied. Filled with 200 c.c. of solution and ordinary (tap) water.
„ 16. 50 c.c. of solution added.
„ 20. Jar emptied. Filled with 300 c.c. of solution and distilled water.
„ 23. 5 c.c. of solution added.
„ 27. 5 c.c. of solution added.
„ 30. Jar emptied. Filled with 330 c.c. of solution and distilled water.
June 3. Jar emptied. Filled with 400 c.c. of solution and distilled water.
And so on.

Comparison of Plant grown as above in Solution A with another similarly grown in Solution B.

	Plant 1 (grown in normal solution).		Plant 2 (grown without nitrates).	
	No. of leaves.	*Height in inches.*	*No. of leaves.*	*Height in inches.*
June 6.	16	54	6	21
„ 12.	18	60	6	21
	Lower leaves are pale, but general appearance healthy.		Evidently not thriving.	

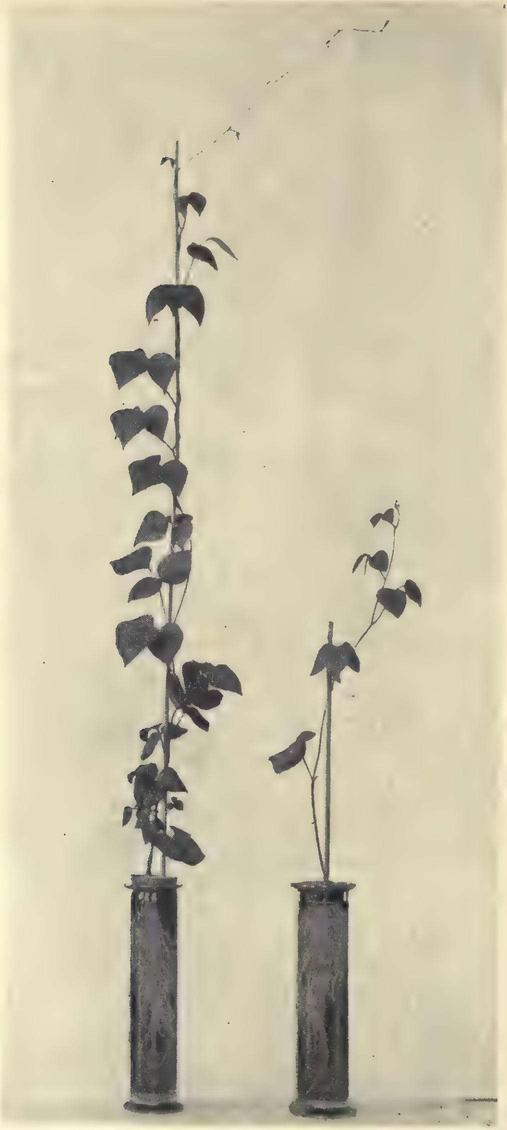

FIG. 23. The same plants as are shown in Fig. 22, photographed a week later on exactly the same scale.

Both plants have excellent roots, those of No. 2 being if anything better than those of No. 1, but No. 1 absorbed the solution much more rapidly.

There is thus a striking difference between the plants, and the only difference between the conditions under which they were grown was that the roots of the thriving one had the opportunity of absorbing nitrates from the food solution and the other had not. Nitrates are salts partly made up of nitrogen. The second plant is evidently starving for want of this element, and yet there was an atmosphere all round it chiefly consisting of the very thing it needed. Two conclusions may be drawn (assuming that other plants are like the bean):

1. Plants cannot be healthy without nitrogen.
2. They cannot utilize the nitrogen of the air.

Notice by the way the three conditions under which nitrogen occurs:

1. Nitrogen as we find it in the air; that is to say, uncombined with any other element.
2. Nitrogen combined with two other elements to form a simple salt, such as potassium nitrate (denoted by the formula KNO_3).
3. Nitrogen combined with several other elements to form the more complex proteins, as, for example, the gluten of wheat. Proteins consist of a combination of carbon, hydrogen, oxygen, nitrogen, and sulphur.

In addition to the proteins, other classes of nitrogenous compounds occur inside the plant. One of these is nicotine, whose formula is $C_{10}H_{14}N_2$. It is an alkaloid.

Plants, then, contain nitrogenous matter. Where do they obtain the nitrogen without which the proteins, the alkaloids, and other similar compounds cannot possibly be built up? The plant in our experiment evidently absorbed nitrates[1] by its roots from the food solution. We naturally look to the soil, then, as a possible source. Does the soil contain nitrates or other compounds from which plants might derive the nitrogen without which they cannot get on? Certainly it does in some parts of the world at least. In Chili, for example, there are the well-known deposits of nitrate of soda, which is a regular export from that country to Europe and elsewhere. In our own country it is often spread on the fields as a manure with much resulting benefit to the crops; but we must consider also the case of ordinary wild plants growing on land that is not manured. How do these plants contrive to live?

EXPERIMENT No. 51.

Apparatus and Material.

Sprouted beans.
Two flower-pots.
Ordinary potting soil.

Enough soil to fill one of the pots must be baked in an oven in order that all the minute living organisms it contains may be killed. It must then be moistened with boiled water. Fill a pot with it, and plant one of the beans in it. Plant a second in the other pot. Allow the beans to grow for some time under the same conditions of light and heat, and at the end of a couple of months or more compare the plants. When they have attained a height of 8 in. or 10 in. remove them from the pots, and carefully wash the soil off their roots. The roots of the bean grown in the soil that was not sterilized will be found to have small swellings here and there on them, but these tubercles will be wanting on the other. If the former is the more vigorous of the two, it would be natural to conclude that the tubercles have got something to do with its better growth. In case one of the beans might, owing to some chance cause, be superior to the other, it will be better to grow a number, say six, under each of the two conditions, and if all those grown in sterilized soil are inferior to the others there will be no doubt that the condition of the soil is accountable for their inferiority, and that the absence of the tubercles will have something to do with the lack of vigour in the plant. As a matter of fact, it has been proved that ordinary garden soil contains certain minute organisms which obtain access to the roots of such plants as beans, and, having got in, cause the swellings or tubercles, which may be compared to the malformations frequently caused in many kinds of plants by the attacks of parasites. These abnormal growths are really a disease, but, strange to say, a useful one, for the bacteria have the power of utilizing the free nitrogen in the air that circulates through the soil and causing it to combine with other elements and form inside the tubercles nitrogen compounds, which are used by the plant with obviously beneficial results. In the sterilized soil all the bacteria have been killed, and the plants grown in this soil have no tubercles and are without the nutriment which the bacteria, had they been present, would have supplied. It should be noted that the plants that are benefited in this extraordinary way all belong to one well-known family of plants—the Leguminosae. To it belong peas, beans, lupins, and many others, both cultivated and wild. The plants of this family, however, are the favoured few. What about the thousands of species that have no tubercles on the roots, and therefore no nitrogenous food prepared for them on the spot by unbidden but not unwelcome guests? There must be some provision for plants that are not peas or beans or lupins or of their kindred. Otherwise they would certainly starve, for they could not exist for more than a very short time on the actual amount of nitrates present in the soil at any given time. Fortunately unseen causes are at work, making good the wastage and ensuring a never-ending supply.

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[1] See Appendix F.

It has now been proved that bacteria similar to those that cause the tubercles exist separate from plants altogether—in the soil itself. These micro-organisms are continually at work in incredible numbers, laying hold of free nitrogen and fixing it in the soluble form accessible to plants.

There is still another source from which the roots of plants may be supplied with nitrogen.

EXPERIMENT NO. 52.

Apparatus and Material.

Crucible.
Garden soil.

Heat some of the soil strongly in the crucible over a fire or bunsen burner.

1. What two changes have occurred?
2. Account for one or both of them.
3. Prove that at least one of the products of the operation does not remain in the crucible.
4. What other material dealt with in a former chapter would give similar results with similar treatment?

The material that gave the soil its dark colour has been burned away. This combustible portion of the soil is really decaying vegetable matter and is known as *humus*. Its importance is great, for it contains many nitrogenous compounds, and it has long been known that it imparts fertility to the soil of which it forms part naturally, or to which it is added artificially. It is easy to believe that this decaying matter, which includes old leaves, dead roots, and stems, in fact all parts of plants, must contain many of the elements of plant food. The difficulty is to understand exactly how these elements are to become available. The compounds of them in the humus are complex and insoluble, and therefore cannot be absorbed by the roots of growing plants. The humus must, of course, decay. This was long looked upon as the most natural thing for dead parts of plants to do under the disintegrating action of various physical forces that were bound to be at work. It is now found that this is a mistaken view of the situation, and within recent years it has been proved that the humus would not decay, would not become available for growing plants, if it were not for the occurrence in the soil of micro-organisms similar to those that form the tubercles of the leguminous plants, and to those that produce nitrates in the soil by the fixation of atmospheric nitrogen.

These bacteria in myriads attack the humus, pull it to bits, so to speak, not only physically, but chemically. The process is by no means simple, and is not accomplished in one stage or by one set of bacteria. The humus yields only to successive invasions of more than one kind of these micro-organisms, and step by step the complex combinations of carbon, hydrogen, oxygen, nitrogen, and sulphur are at last reduced from their insoluble and useless condition to simple soluble and fertilizing salts, which plants can lay hold of and thrive upon, among them being the specially desirable nitrates.

Notice four ways in which plants like the bean may obtain nitrogenous combinations by the roots:

1. Bacteria gain access to the roots and in the tubercles that result form nitrogenous compounds.
2. Nitrates are formed in the soil itself by bacteria that fix the free nitrogen of the air.
3. Nitrates are also formed in the disintegration of the humus by bacterial agency.
4. Nitric acid and ammonia both occur in the air and get carried into the soil by the rain.

Finally, we must remember that some plants obtain nitrogenous food through a different channel altogether—not by their roots, but by their leaves.

EXPERIMENT No. 53.

Apparatus and Material.

Plants of *Drosera rotundifolia* (Sundew).
Moss.
Plates.
Bell-jars.

Allow the plants to grow for some time on damp moss on a plate. Cover each plate with a bell-jar to keep off dust and insects.

Each plant has a number of round-stalked leaves, and each leaf has a number of hairs or tentacles growing from its upper surface. Examine one of the leaves.

1. About how many tentacles are there on a single leaf?
2. How do the tentacles differ from ordinary hairs?

3. How do the tentacles at the centre of the leaf differ from those at the edge—

(*a*) in size?

(*b*) in colour?

(*c*) in relation to the surface of the leaf?

After the plants have been growing for some time under the bell-jars and have accommodated themselves to their new conditions, take a minute piece of raw beef and very carefully place it on the centre of one of the leaves. Examine it after an hour or two.

1. What has taken place?
2. If any of the tentacles have moved, settle which.
3. What conclusion would you draw if movement has taken place in tentacles not actually touched by the piece of meat?

Freshly collected specimens of the plant often have a number of dead insects sticking to the leaves. By the gradual absorption of these the plant obtains nitrogenous nourishment.

In order to be convinced that this plant is really benefited by this method of feeding, Darwin made the following experiment:

Plants were grown on six plates, and the plants on each plate were divided into two sets. There were thus twelve sets altogether. One set on each plate was fed with meat, and the other sets got no animal food. After ten days there was a distinct difference between the 'fed' ones and the 'starved' ones. Later, the differences were much more striking, as shown by comparison of various details. There was therefore no doubt whatever that the Sundew got great benefit from animal food.

Notice the following general conclusions:

1. Nitrogen compounds enter the plant by its roots, or are produced in the roots themselves.
2. This nourishment is mainly due to bacterial activity, but rain-water supplies minute quantities of nitrogenous compounds.
3. In the absence of micro-organisms vegetation would come to a standstill.
4. In exceptional cases nitrogenous compounds may be obtained by the help of the leaves.

After all, it is the nitrogen of the air that the plants are really using, although it reaches them in the indirect ways already described. The supply of nitrogen in the air is boundless, and as long as the bacteria keep at work there will always be a supply of nitrates. Agricultural land, however, is specially apt to become impoverished, as the farmers carry away the crop, and with it the nitrogenous matter that would have been returned to the soil had the crop been allowed to decay where it grew. Hence the need for a continual supply of nitrogenous manure. The beds in Chili, which have been supplying nitrate of soda for many years to this and other countries, will by and by be exhausted. Processes are now in operation for dealing with the free nitrogen of the air, which plants cannot directly use, and causing it to combine and form nitrates which can be spread upon the soil and absorbed in solution by the roots. The production of these and their employment as manures will increase the fertility of the arable land of the world, and enable it to support a larger population. In the artificial preparation of nitrates we see the hand of man forcing the environment of the vegetable kingdom to be of more service than it naturally is.

CHAPTER VIII

THE INFLUENCE OF HEAT

THE Sahara is a desert solely on account of the want of water. Thousands of square miles of land in the Arctic and Antarctic regions are as devoid of vegetation as the great desert, but for a different reason. It is heat that is wanting there. The importance of this form of energy is enormous. It affects plants at all stages of their growth, and regulates their activities. Reference has been made in Chapter I to the effect of heat on germination, and in Chapter II to the generation of heat by plants, but it is desirable to bring more of the facts together, and incorporate them in a more general view of the relations of plants to heat. The effect of heat is felt at the very earliest stages of a plant's development.

EXPERIMENT NO. 54.

Apparatus and Material.

Mustard seeds that have been soaked for a day.
Blocks of ice.

Place some of the seeds in a small bottle, and keep them at about 15° C. The rest we put in another bottle, which may be fixed by a metal stand in a pail of water with some ice in it to keep down the temperature. Both sets may be kept in the dark. Examine the seeds after 24 hours and again after 48 hours. Temperature should be taken periodically.

1. What is the effect of low temperature?

2. How would you arrange to try the effect of temperatures a good deal higher than 60° F.?

3. If seeds are placed in an oven they will certainly not grow. In what respect is the experiment unsatisfactory?

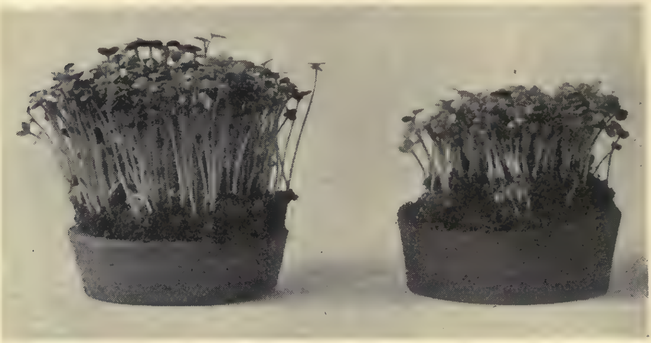

FIG. 24. Experiment showing the effect of heat. The two sets of mustard seedlings were grown in the same hothouse, the one at the warmer, the other at the cooler end. The average difference of temperature was about 3° or 4° Centigrade.

Another somewhat similar experiment may be made with beans or peas.

EXPERIMENT NO. 55.

Apparatus and Material.

Two sprouted beans with roots about 1 in. in length.
Pots of soil.
Thermometers.

Measure the roots, and record the length of each in millimetres. Then plant the beans, and put one in a warm place and the other in one cooler by about 10° C. Take readings at intervals, so that an average temperature for each may be arrived at. After two days remove the beans from the pots and measure the roots. Replace the beans, and measure again after other two days, and a third time after a like period. Tabulate the lengths.

1. What is the total increase in each case?
2. What is the average daily increase?
3. How may the roots be measured if they are not straight?

If heat is necessary in the first beginnings of growth, it is also so in all the subsequent stages of the plant's life-history, in the course of which we have the elongation of root and stem, the unfolding of the leaves, the formation and opening of the flowers, and then finally the ripening of fruit and seed. These outward phenomena, moreover, are only the expression of the various processes at work inside the plant. And it is generally not difficult to prove that these important vital functions are markedly controlled by temperature.

EXPERIMENT No. 56.

Apparatus and Material.

Fresh twig.
Bottle fitted with 3-holed stopper.
Thermometer.
Tube with funnel at end and stop-cock below it.
Thermometer tubing (or capillary tubing).

Take about 6 inches of the thermometer tubing and bend it so that the one arm (2″) is at right angles to the other (4″). Fit the shorter arm into one of the holes in the stopper. Do the same with the straight tube and with the twig.[1] Fill the bottle with water and (stop-cock being open) press the stopper in. When the water has risen above the stop-cock close the latter. The horizontal arm should now be full, and if all fittings are tight the water will travel backwards along it. Note the time it takes to do so over a marked distance. When it has got past the second mark, start the experiment afresh by opening and closing the stop-cock. Take several other readings and get the average time. Take another set of readings in a warmer place. It will be found that the plant takes in water more rapidly when the temperature is raised, and we may safely say that if it is taking in moisture more rapidly it is also giving vapour off more rapidly from the leaves to the air. The former operation is known as absorption and the latter as transpiration. Both are most important for the plant, and, as we see, both are under the influence of temperature.

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[1] See Appendix E, p. 196.

1. What advantage is it for a plant to have a rapid transpiration current?

2. Under what circumstances would rapid transpiration be a disadvantage?

None of the vital activities of the plant is more important than breathing. Is it also affected by changes of temperature?

Experiment No. 57.

Apparatus and Material.

Twelve soaked peas.
Two test-tubes, both of the same size.
Mercury.
Two metal stands.
Two troughs.
Flat piece of rubber.
Pail.
Ice.
Mounted needle.
Caustic solution.
Pipettes.

Skin the peas. Fill one tube with mercury and invert it in a basin of mercury, securing it in position by means of a metal stand. Lift one of the peas with the needle and then press it down under the mercury and inside the mouth of the tube. Withdraw the needle. The released pea rises to the round end of the tube. Put in four or five of the peas in this way. Deal with the other tube in exactly the same way. Put one of the experiments in a pail of water kept cool by pieces of ice, fresh ice being added when necessary. Both experiments are now to be placed in the dark. Put a thermometer beside the tube in the pail and another beside the other tube. Take readings at sufficiently frequent intervals to give some idea of the average temperature in each case. After two or three days compare the results.

As the mercury in the tube kept at the higher temperature has been forced down farther than the mercury in the colder tube, we can only conclude that the peas in the former case have been breathing more actively than the peas in the latter. The gas that fills the space above the mercury is carbon dioxide, as was proved in Experiment No. 22, Chapter III. As the amount of breath is a measure of the amount of energy that has been developed, the extra heat has produced extra energy, surely a most beneficial result.

We may also refer to the very important process that goes on in green plants under the influence of light, namely, the formation of starch or other carbohydrate. It has been already proved in a former chapter that, as the carbohydrates are formed in the cells of the leaf, oxygen is liberated, the amount of the latter being in proportion to the amount of carbohydrate formed.

EXPERIMENT NO. 58.

Apparatus and Material.

Elodea Canadense.
Beakers.
Glass rod.

Affix a portion of the plant lightly, by a small piece of thread, to the stirring-rod, so that a cut end may be kept under the surface of the water in the beaker. Place the apparatus in full sunshine. Small bubbles escape from the cut end and rise to the surface. Count the number that come off in a given time, say three minutes. Repeat this several times to see if the rate is steady. Having found out this, take the temperature of the water and then transfer the plant to water 5° or 10° C. warmer. Again take a record of the bubbles. Finally, try the effect of ice-cold water.

The bubbles are composed of oxygen, and as more of them are set free when the temperature is high (but not too high) than when it is low, we are entitled to say that temperature controls the amount of carbohydrate formed. As carbohydrates form part of the plant's food, heat therefore is the cause of another highly important and beneficial result. By its action the plant is better fed. To sum up, in cold the plant absorbs slowly, transpires slowly, has little energy, forms little food. Raise the temperature and there is a change. The absorption of water becomes more rapid. So does the transpiration. The plant is more energetic and builds up larger amounts of food supplies.

If it is desired to compare the effect of light with the effect of heat, first ascertain as before the rate at which the bubbles are given off by *Elodea* in full sunlight. Then move the experiment to a window lighted from the north (or at least out of the sun) and determine to what extent the rate at which the bubbles are given off is affected by the reduction in the intensity of the light. Finally, bring back the plant to a sunny window which can be thoroughly darkened by letting down a thick blind or by closing a shutter. When the stream of bubbles is again established, get some one to attend to the blind or shutter. By the aid of an artificial light keep your eye on the plant, and note very carefully what happens when daylight is entirely cut off. Settle whether

1. The bubbles increase in number.
2. Or decrease.
3. Or continue to come off at the same rate.
4. Or stop altogether.

We have now seen what a change of temperature does to the plant, but there is another side to the question. The plant may itself effect a change of temperature in itself or in the air. This has been already shown in Experiment No. 14, but it may be demonstrated again with different material.

Experiment No. 59.

Apparatus and Material.

Baker's yeast.
Flour.
Two jars.
Mortar and pestle.

Mix up some of the flour and water into a smooth paste. Put this in one of the jars, making it about half full, and put water to the same depth in the other. Mix up about half an ounce of yeast in a small quantity of water, and add an equal quantity of this mixture to each jar. Ascertain with the thermometer whether the temperature is the same in each case. After a little time, take temperatures again.

If the temperature in the jar containing the flour is the higher, this will show that the yeast is feeding on the flour, and that in the slow combustion of this food in the yeast-cells heat is generated.

1. What gas will be formed? Give reasons for your answer.
2. Is there any sign that gas is being formed?
3. How could it be tested?

The generation of heat in the plant body must, of course, to a slight extent, affect the surrounding air. There is, however, another way in which plants, especially green leafy plants, affect the temperature of the atmosphere, as may be illustrated by the following experiment.

EXPERIMENT NO. 60.

Apparatus.

Flask with rubber stopper, fitted with bent tube.
Metal stand and ring.
Thermometer.
Calorimeter.
Chemical balance.

Weigh the calorimeter empty. Fill it three-fourths full of water and weigh again. Take the temperature of the water. Put water in the flask, and, when it boils, conduct the steam into the water in the calorimeter. The temperature of the water immediately begins to rise. Allow it to go on doing so till the thermometer registers 60 to 80 degrees Centigrade. Withdraw the tube, and weigh the calorimeter and its contents.

If 100 grammes of steam were added to 100 grammes of water at 15° C. we should expect to get 200 grammes of water at 57·5° C., but in our experiment we find that 7 or 8 grammes of steam have raised the temperature more than we might have expected 100 grammes to do.

The secret of this is that when water passes into vapour (or steam) a great deal of heat is absorbed. In the case of a boiling kettle, where water is very rapidly being turned into steam, the necessary heat is supplied by the fire. Owing to its action, the temperature of the water for some time continues to rise, but after the water is boiling, although the fire goes on supplying heat, the water gets no hotter, all the heat being now used up in changing the water from the liquid to the gaseous state. The heat seems to disappear. In other words, it becomes *latent*.[1] When, on the other hand, condensation takes place, the resulting liquid has a higher temperature than might have been anticipated. This is owing to the reappearance of the lost heat. From this we see that whenever water turns into vapour, there must be a cooling in the environment. This change from the liquid to the gaseous state is what occurs in vigorous green leaves when they transpire. Consequently, the temperature of the leaf itself, and also of the surrounding air, will be lowered. As the rate at which the change is taking place is much slower than in the case of the boiling kettle, the effect is not very obvious, and might be regarded as insignificant; but consider the weight of water that escapes into the air as vapour, not from one leaf only, but from the thousands, or tens of thousands, or even millions of leaves on a single tree. And then if we take into account the vegetation of the whole globe, we can realize the enormous amount of heat of which the atmosphere is temporarily robbed in the course of a year. Although the amount lost at one place is small, still it can be felt. Every one has experienced the pleasant coolness of a wood on a hot summer day. Naturally one attributes this to the shade afforded by the trees. But this is not the whole explanation. On such a day transpiration is active and much heat is being made latent at the expense of the air, which thus has a delightful freshness imparted to it.

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[1] See Appendix F: Latent Heat.

The cooling that takes place is not only acceptable to those who seek refuge in the wood from a broiling sun, but will tend to produce gentle movements of the air, which are, of course, beneficial to the plants themselves.

After all, however, the most notable fact is the extraordinary influence of outside heat on vegetation. Cold has a deadening effect, but when the warming rays of the sun fall on a country-side, the plants respond at once, and activity spreads through all their organs. This activity does not demonstrate itself in outward movement, but it is none the less real, and the various functions that are stirred to energetic performance co-operate to produce the remarkable result that is summed up in the one word—growth. This may be manifested in various ways. It may show itself in the addition of new wood to the stem, in the elongation of the root and its branches, in the enlargement of young leaves, and so on. With every such increase the plant gets more power over the environment. With an extended root it can absorb more material in solution. With a thicker stem it can transmit this more copious supply through every branch to every leaf. With more leaf-surface, transpiration is increased in amount, and a larger quantity of carbon is captured from the surrounding air.

After the plant has produced all or most of its vegetable organs for the season, the energy which the sun still continues to impart is diverted to the development of flowers, and later still to the ripening of the seed. In the case of cereal crops, the later work of the plant is the manufacture of the carbohydrates and the nitrogenous compounds with which the grains are packed. If in summer the heat is deficient, the yield will be poor. Mankind feeds not only by the light of the sun, as was pointed out in Chapter IV, but also by its heat.

CHAPTER IX

REPRODUCTION

In the preceding chapters plants have been considered in their relation to air, to water, soil, and so on. Another factor to be taken into account is time. After a longer or shorter period of successful struggle, the plant at last gives in, and its existence comes to an end. The life of the humble herb is short. In spring it bursts from the seed, flowers in summer, bears fruit in autumn, and dies either then or before winter is far advanced. Other plants, such as trees, hold out longer, and may, as a matter of fact, reach the age of a thousand years or more. At last, however, these patriarchs of the forest end their days in quiet decay, unless they are, as often happens, dashed to earth in some violent gale. So all individual plants disappear sooner or later. In spite of this fact, vegetation continues to cover the earth. As fast as old plants die, even faster, new ones spring up to take their place.

This making of new plants is known as *reproduction*. It is exemplified by every division of the vegetable kingdom, and is in progress at all seasons. In our own country, though most obvious between spring and autumn, some of the lower orders of plants accomplish it even in winter. One of the most remarkable facts connected with it is the countless numbers of new plants that are produced. Think, for example, of a hillside

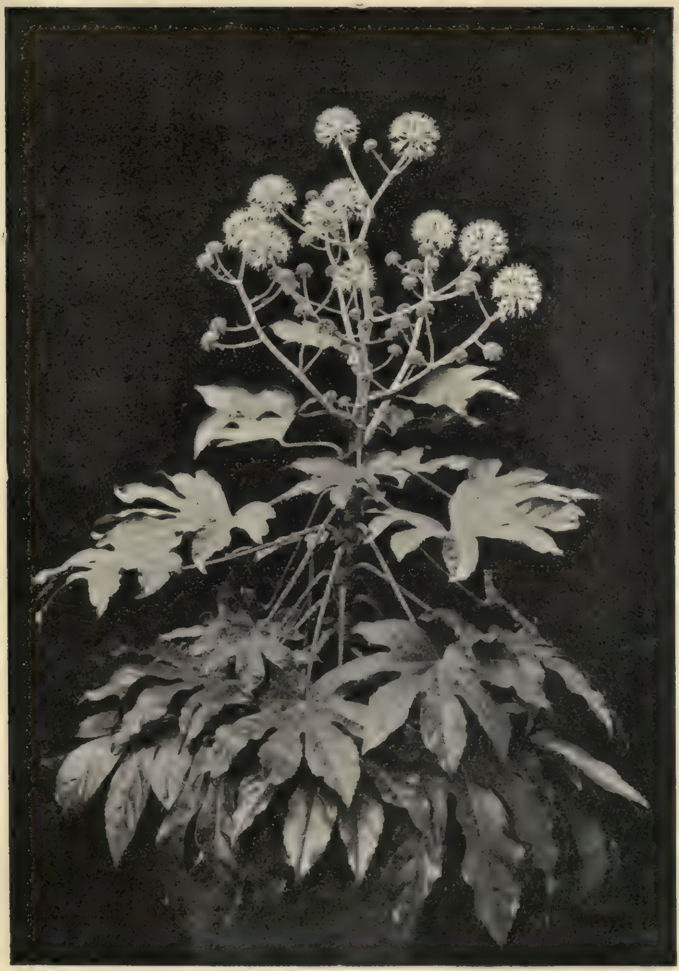


FIG. 25. An aralia with the flowers (the reproductive organs) occupying a part of the plant by themselves.

purple with heather, and consider the millions of small flowers required to produce this fine colour-effect over miles of country. Each separate blossom is, so to speak, a factory for turning out new heather plants. If all new herbs, shrubs, and trees that are formed had chance and room to grow there would very soon be vegetation enough to cover a world hundreds of times as large as our own. As there is such variety of size and shape, such variety of structure, from the simple unicellular alga, with no organs at all, to the stately tree with its endless ramification and countless leaves, it is not surprising that there should be variety in methods of reproduction. The best-known method of all is, of course, the one in which seed plays a part. Flowers, without which no seed whatever can be formed, are really collections of reproductive organs.

EXPERIMENT NO. 61.

Apparatus and Material.

White mustard seed.
Pot with soil.
Plate.
Piece of flannel.

Sow some of the seed on the surface of the soil in the pot, and some on the flannel after it has been made quite wet. Cover each set with a bell-jar or inverted tumbler and watch results.

1. What is the first change to occur?
2. How soon does the new plant show itself?
3. What part appears first?
4. In what direction does that part grow?
5. How many leaves has the plant at first?
6. Where is there a bud?

A plant that thus springs from a seed is called a *seedling*, and it is remarkably different from the seed. Other kinds may be sown for comparison with the mustard. Consider the case of the broad bean. You put into the ground a dull-coloured object about as hard as a stone and looking as dead. In a week or ten days you have a soft-fleshed seedling of a lively green, daily getting bigger and unfolding new parts. To observe the development of a seedling like this is indeed to witness a transformation scene. Where does the seedling come from?

EXAMINATION OF BEAN.

Material.

Broad beans (soaked).

Remove the skin, and examine what remains. It will readily divide into two large flat parts, which, however, should not come entirely apart. Note the line of division along the edge.

1. Find two leaves (called *cotyledons*), a root, and the beginning of the stem in the shape of a bud.
2. Why should the cotyledons be so much larger than the other parts?
3. Why should they be white?
4. What conclusion do you form from the fact that the cotyledons, root, and stem-bud are all fixed together?
5. Why should all the parts be so closely packed while in a full-grown plant they are as far apart as possible?

All these parts put together as they are form a miniature plant called the *embryo*. Inside the seed, then, we have found the plant that afterwards comes out and forms the seedling. Having examined some of the later

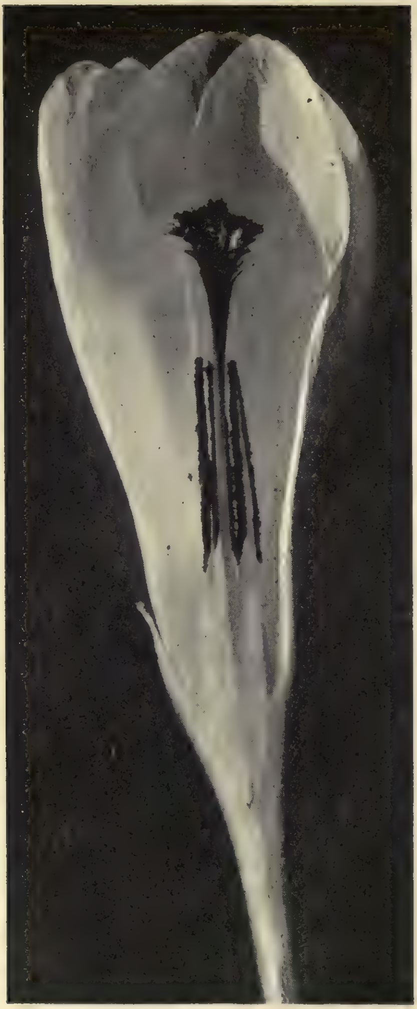


FIG. 26. Part of flower of crocus showing the stigmas higher up than the three stamens. Note that the anthers of the latter have already shed their pollen.

stages in reproduction—the condition of the embryo in the ripe seed and the emergence of the seedling—let us now turn our attention, not to the final result, but to the earlier stages. Can we find a seed, or something that represents it, without an embryo at all? If so, can we next discover where the embryo comes from, or what brings it into existence?

EXAMINATION OF UNOPENED FLOWERS (Figs. 26 and 27).

Apparatus and Material.

Unopened flowers of crocus tulip, daffodil, or wallflower.
Magnifying glass.

Make a lengthwise section of the central portion of the flower, when minute roundish bodies should be laid bare.

1. What is their colour, size, and shape?
2. How would you describe their surface?
3. Are they loose or fixed?
4. In how many cavities are they contained?
5. Count or estimate their number.

As these bodies are placed exactly where seeds will be found later on, it is very natural to speak of them as young seeds. This, however, would be incorrect, and we must speak of them as *ovules*. It is true that they may develop into seeds, but it is also true that they may not. As they are at present, there is a very great difference between them and seeds. They are without the one thing that makes a seed a seed—they have no embryo, and this defect cannot be remedied by just letting them grow a little longer. They are certainly intended to be seeds, but unless a stimulus from without reaches them they cannot pass beyond their present stage. What the required stimulus is, we shall see later on.

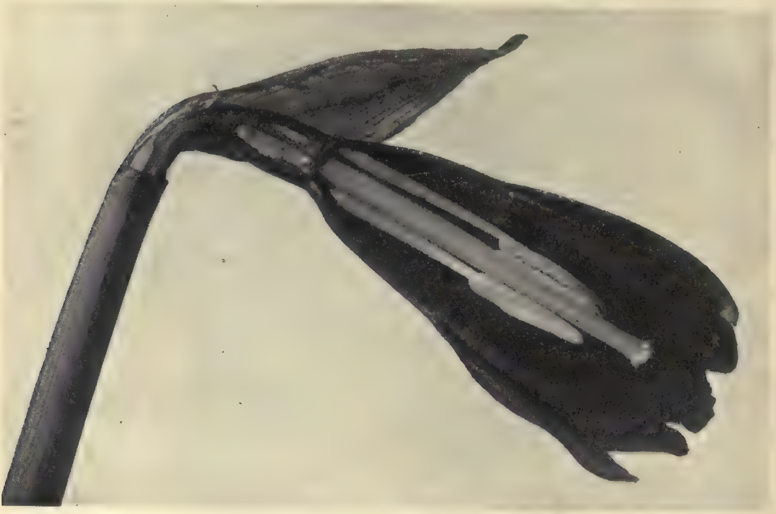


FIG. 27. Section of flower of daffodil. The ovules are seen a little to the right of the bend. The long straight style runs up the middle of the flower and ends in three stigmas. Of the six stamens three are to be seen, one being partly hidden by the style. The anther of the uppermost stamen is just beginning to burst.

EXPERIMENT NO. 62.

Apparatus and Material.

Six tulips in pots.
Pair of scissors with long and fine points.

From the tulips in three of the pots remove, by help of the scissors or otherwise, the six stamens to be found in each. This must be done before the flower opens, when the stamens should not show any yellow dust on their surface. Care should be taken to injure the coloured flower-leaves as little as possible. The other three plants are to be left untouched to act as controls. The two sets of pots are then to be kept well separate, and after a month or so examine the flowers. If those from which the stamens were removed are forming no seed, while the others are doing so, as may be judged from the enlargement of the seed-vessel that will take place in that event, then this simple experiment proves that seed does not set without stamens. The stimulus the ovules require is a stimulus from the stamens. This is no recently discovered fact, for from ancient writers we learn that centuries ago the Arabs knew how to make the date-palm form fruit. In this tree the staminate and pistillate flowers are not found on the same individual, and the Arabs regularly, at the proper season, climbed the trees bearing staminate flowers, cut off a supply of

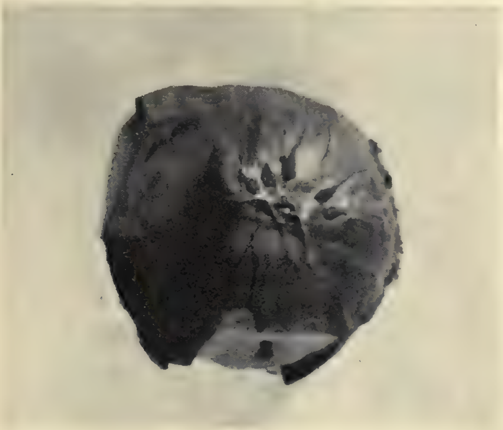


FIG. 28. Portion of seed of oak, with five small unfertilized ovules adhering to it. The seed itself is in the sixth, the only fertilized one.

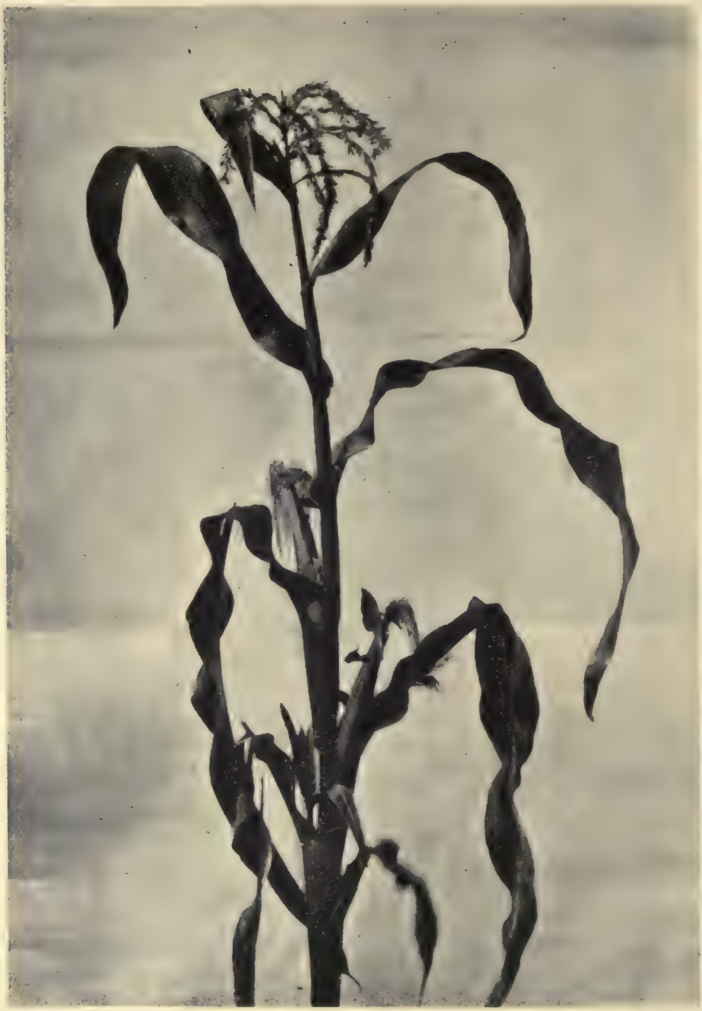


FIG. 29. Maize has two kinds of flowers, staminate ones at the top of the plant and pistillate ones about the middle. From each collection of the latter hangs a tassel of thread-like stigmas, which catch the pollen as it falls.

these, and brought them into contact with the pistillate flowers on other palms, thus greatly improving the crop of dates. Although the Arabs knew the benefit of this treatment, they did not know exactly how the stamens acted. Let us now consider this point. How are the stamens to have any effect on ovules which it seems impossible for them to get at. The ovules are completely cut off from the outside, being fixed inside a closed chamber, the *ovary*. How is the influence of the stamens to penetrate to them in this position? The ovules cannot come out. Can the stamens get in?

EXAMINATION OF STAMENS.

Apparatus and Material.

Tulips or other flowers at distinctly different stages.
Magnifying glass.

The stages of the flowers, as shown by the condition of the brightly-coloured flower-leaves, will be equally evident from an examination of the stamens they enclose. Remove a selection of the latter, and lay them out in a series, illustrating the steps by which their final condition is arrived at. The magnifying glass, though not necessary, may be used to make the details clearer.

1. How does the surface of an older stamen differ from the surface of a much younger one?
2. Find, if possible, a stamen which, when drawn lightly across a dark piece of cloth, leaves no mark.
3. What kind of mark do some of the stamens leave when thus treated?
4. Is it a younger or an older stamen that leaves the mark?
5. If any sign of splitting is noticed, settle in what direction it runs and where it begins.

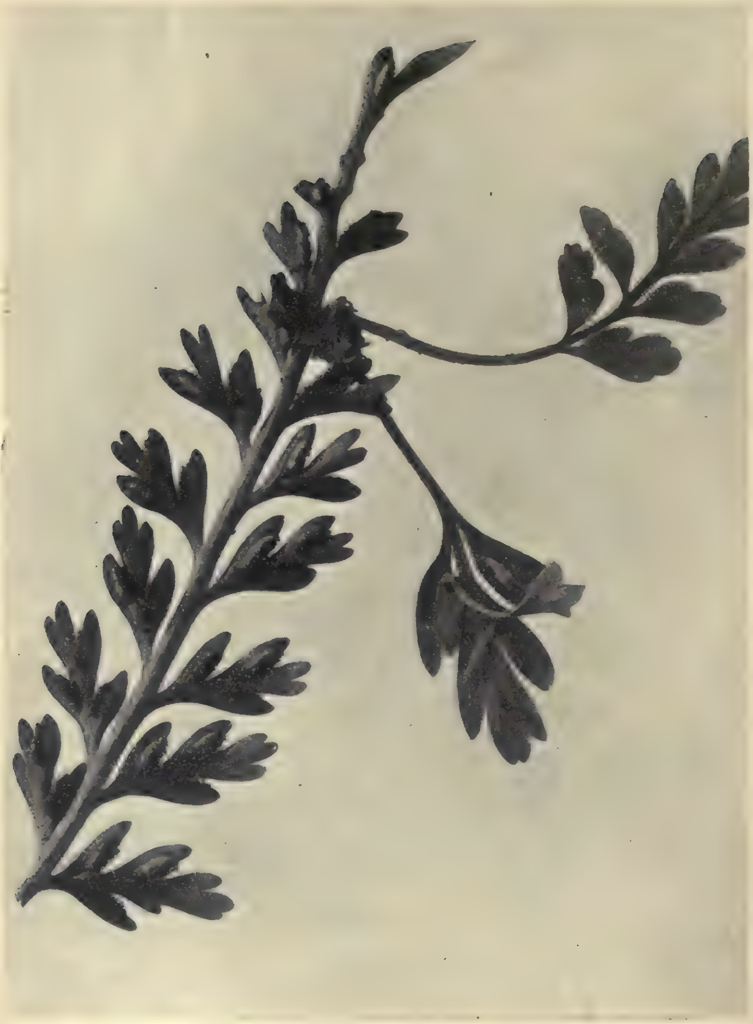


FIG. 30. Back of portion of fern frond (*Asplenium*). This fern, like many other plants, can reproduce itself in more than one way. The numerous narrowly elliptic collections of spore-cases seen on most of the subdivisions of the surface represent a step leading up to a sexual method of reproduction. The young fern with young fronds is really growing from a bud on the upper surface of the parent frond and represents an asexual process.

After these points have been settled, it will be evident that the *anther* is really a sort of box which, when ripe, splits in such a way that its powdery contents are thrown out. This yellow dust or *pollen* is light and dry, and can easily be blown about by the wind or otherwise transported. If the stamen as a whole cannot leave its place, it can send its influence to a distance by means of the pollen, which is really part of itself. Let us now see what pollen looks like.

POLLEN UNDER THE MICROSCOPE.

Apparatus and Material.

Newly-opened flowers.
Microscope.
Slides and cover-glasses.

Put a drop of water on the slide, and touch it with a burst anther. Some of the pollen will come off. Apply the cover-glass, and then examine the slide, first under a lower and then under a higher power. Examine in this way pollen from several species of plants. Various facts will then be evident.

1. The dust will be found to consist of distinct grains.
2. The grains are very small.
3. They have a definite shape.
4. This shape varies with the kind of plant.

Many flowers have spherical grains, but elliptical ones also occur.

5. The surface of the grain is not always smooth. Often it has projections, and may be beautifully marked.
6. The grains are semi-transparent, and are neither solid bodies nor empty chambers, as may be

inferred from their frequently bursting when mounted and ejecting their contents into the water.

The size of a pollen grain may, without any difficulty, be approximately determined.

MEASUREMENT OF POLLEN GRAIN.

Apparatus and Material.

Fresh pollen.
Microscope.
Stage micrometer, marked in thousandths of an inch.
Pen with fine point.
Indian ink.

Mount pollen grains as before, and bring them into focus under a fairly high power. With the pen and ink mark on the glass of the eye-piece the ends of a diameter of one of the grains. Remove the slide, and put in its place the stage micrometer. By means of its ruled lines find the distance between the two spots on the eye-piece.

Some pollen grains have actually got a diameter no longer than ·0025 mm. Supposing such a grain to be spherical, we can, by the usual formula, calculate its volume, and, assuming its density to be that of water, we can go a step farther and make a rough estimate of its weight. In some cases, it works out at one ten-millionth of a milligramme. Such is the pollen grain, the stamen's delegate, the bearer of its stimulus to the ovule.

Having weighed the passenger, let us next consider the journey to be made. For the pollen must, by some means or other, be transferred from the stamen that produced it to an ovule in the same or in another flower.

The journey may be considered as consisting of two stages—the first from the stamen to the stigma, and the second from the stigma to the ovule.

The first stage may be a very easy one, for sometimes the pollen falls from a stamen to a stigma that is close beside it in the same flower, the distance being measured possibly in fractions of an inch. The matter, however, is frequently not so simple as this. In many flowers special arrangements exist for preventing stamens shedding their fertilizing dust on the stigma that seems so conveniently near. A longer journey is therefore necessary, but by aid of bee or wind the pollen accomplishes it, and in due course reaches the arrival platform in the shape of a stigma of another flower, whose distance from the starting-point may, under these conditions, be measured by whole inches, whole yards, or even miles. The act of arrival is known as the *pollination* of the stigma, which by its sticky surface or by its hairs detains the grains deposited on it. The next stage is certainly short enough, but seems more difficult. How is the pollen grain on the outside of a box, with no clear passage to the interior, to reach the ovule imprisoned there?

EXPERIMENT NO. 63.

Apparatus and Material.

Fresh flowers, microscope, &c.
Solution of sugar and water (5 to 10 per cent.).

Mount some pollen in a drop of the solution. Examine under the microscope, and then set aside for an hour or two, taking precautions to prevent the solution under the cover-glass from drying up. If the pollen was in good condition, in this time some of the grains will have developed tubes whose length compared with the size of the grain is considerable.

What happens in a solution of sugar happens also on the stigma, and the delicate tube that comes from each grain gradually, as it elongates, worms its way down through the loose tissue of the style, and eventually reaches the ovary. Thus although the pollen grain itself remains where it settled, its contents, which are really the greatest and best part of itself, by moving along the inside of the tube, arrive where the latter arrives—that is, as has just been said, in the ovary itself. The tube, be it noted, is closed at its free end, and the contents are not lost on the way.

But the goal has not yet been attained. It is not enough for the pollen tube to be in the ovary. It must actually reach an individual ovule. Even this is not all. The tube must not only reach the ovule, it must find the *micropyle*, the one and only and most minute approach to the interior. Finding this pore, the tube works its way in, and as a result the contents of the tube, which are really the contents of the pollen grain, are enabled to mingle with a very important interior portion of the ovule, the *egg-cell*, and this union is known as *fertilization*.

A stimulus has been imparted, and the changes that follow are remarkable. The egg exhibits astonishing activity, and very soon, out of apparently formless matter, produces the shape of a plant, with root and stem and leaves. The egg is now an embryo, and the ovule that would otherwise have shrivelled up into nothing has been changed into a seed, which in due course ripens, and later, when sown, gives rise to a new plant.

So we see that the arrival or non-arrival of the pollen tube at the proper time settles whether a new plant will be produced or whether it will not. With the new plant we must include all that it grows to, and all that it gives rise to, if we wish to estimate the total result.

Take, for example, a young acorn. If one of its ovules gets fertilized by a pollen tube an embryo oak is formed in the seed. This embryo, under fortunate conditions, will develop into a tree that may continue growing for centuries, producing in that time thousands of acorns like the one from which it grew. All its energy, shown not merely in this reproductive activity, but also in extensive development of stem and branch and in the annual renewal of its mantle of green leaves, is to be traced to a pollen grain so small that we cannot see it without a microscope, and so light that we cannot weigh it even with the most delicate balance. But we shall certainly miss a very important part of the truth if we think of fertilization as simply a stimulus—a setting agoing of the works. It is more than this.

Suppose a primrose is fertilized by pollen from another primrose plant, the resulting seed will grow into a plant that will not be distinguishable in any important respect either from the plant that bore the seed or from the plant that supplied the pollen. This is what is to be expected. But suppose the ovule of a primrose is fertilized by pollen from a closely related though different species, what then? What sort of plant will grow from a seed produced in this way? It will not be surprising if it resembles the plant on which the seed was formed. What is remarkable is the actual fact that it resembles this plant only in some of its characters, and in others it resembles the plant from which the pollen was derived. The only way these characters could have been acquired is through the minute quantity of matter in the pollen grain, which therefore not only acts as a stimulus, but hands on to the ovule a heritage of qualities.

A plant formed in this way is known as a *hybrid*, and is interesting because in it we are able to apportion its characters to one or other of the parents, some of them being distinctly due to the influence of the pollen. In cases of ordinary fertilization—that is, when an ovule is fertilized by pollen from the same flower or from the same plant, or from the same species of plant—the particular characters which the resulting plant owes to the pollen cannot in the same way be distinguished from those contributed by the ovule itself. But this does not alter the fact that the pollen is just as potent in the one case as in the other. In the case of the hybrid, the transmission of characters is obvious. In the case of normal fertilization, characters are transmitted in exactly the same way. The only difficulty is to detect them.

The seed, then, with its enclosed embryo, is the result of the union of two reproductive elements, the one being the contents of the egg-cell in the ovule, the other the contents of the pollen grain. Reproduction of this kind is described as sexual, and although most familiar in the case of flowering plants, is to be found through almost the whole vegetable kingdom.

We have already seen in preceding chapters that plants, which at first sight seem to be so different from animals, really agree with them in many fundamental points. They are both dependent upon the oxygen of the air, and their breathing results in the same product (carbon dioxide). Both feed, grow, and ultimately die, and when we consider reproduction, we find here, too, between plants and animals important points of agreement.

APPENDIX A

HISTORICAL AND OTHER EXPERIMENTS

Relation of Plants to the Air.

Priestley, the discoverer of oxygen, made some experiments with plants. Here is one of them.

'Accordingly on the 17th of August, 1771, I put a sprig of mint into a quantity of air in which a wax candle had burned out and found that on the 27th of the same month another candle burned perfectly well in it . . .'

What does this experiment prove?

See *A History of Botany in the United Kingdom*, p. 292.

Bleeding of the Vine.

An early and famous English experimenter in vegetable physiology, Stephen Hales, tells that he hit upon one of his experiments by mere accident. An old vine-stem had been cut at the wrong season and he feared the plant would be killed by the bleeding which ensued. So he tied a piece of bladder over the cut end where the sap was escaping.

What do you think happened?

Account for this.

What experiment in the foregoing chapters shows a similar result?

About what time of the year did Hales cut the vine?

Hales's Sunflower Experiment—July 1724.

He took a large pot with a sunflower growing in it. The surface of the soil in the pot was covered with a thin plate of lead and all the joinings were carefully cemented. The pot and the plant were weighed night and morning, 'for 15 several days from July 3 to August 8'. Finally, the plant was cut off close to the leaden plate and the stump was cemented. The pot now lost '2 ounces every 12 hours day'.

What was the purpose of the experiment and what was the use of cutting down the plant and weighing the pot?

Van Helmont's Experiment.

This is the earliest scientific experiment in vegetable physiology of which any account remains.

A quantity of earth which had been dried and weighed was put in a pot and a willow-branch was then planted in it. The earth (when dry) weighed 200 lb. and the willow-branch weighed 5 lb. Protected from dust the branch was kept growing in the pot for five years, being watered daily. At the end of this period the soil was again dried and found to weigh only 2 oz. less than it did at first, whereas the willow-branch had gained 164 lb. Van Helmont concluded that the gain in weight was due to the water which had got changed into plant substance.

Give the true explanation of the increase.

Nehemiah Grew (1641 to 1712).

'Take a Box of *Moulds* with a hole bored in the bottom, wide enough to admit the *Stalk* of a *Plant*, and set it upon stilts half a yard or more above the ground. Then lodge in the *Mould* some *Plant*, for example a *Bean*, in such sort that the *Root* of the *Bean* standing in the *Moulds* may poynt upwards, the *Stalk* towards the ground.'

What would happen and what does the experiment prove?

Source of Nitrogen.

Various kinds of plants were grown in calcined soil (that is, soil freed from nitrogenous compounds by the action of heat) and the air supplied to them in the glass shades under which they were grown was first freed from any trace of ammonia (NH_3).

By comparing the amount of nitrogen present in the seed with the amount present at the end of the experiment in the plant, soil, and pot it was found that practically no increase had taken place.

What conclusion can be drawn from this result?

Among the plants experimented upon were wheat, barley, oats, peas, and beans. In which of these would you most expect an increase to occur? What prevented this happening?

Mariotte's Experiment.

(Mariotte died in Paris in 1684.)

A piece of branch was cut off and placed so that some of its leaves were under water while the others were exposed to the air. The latter remained quite fresh for a considerable time.

Draw a conclusion from this.

Point out what is faulty or erroneous in the following quotations.

1. 'Every ripe seed in a dry state is a concentration of carbon, which when dissolved by moisture and its particles set in motion by sun heat is in a fit state to combine with the oxygen in the atmosphere, and thus to form the carbonic acid gas which is the nourishment of the expanding plant.'

2. 'Water is made up of two gases, and so, in taking in water, plants take in gases. But they also *feed on gases* that are *in the air*.'

3. 'In the hottest weather a plant keeps cool because it is able to send out into the air everything that it does not want.'

4. 'When night falls, the cells which absorb and split up the carbonic acid must rest from that good work; and now they truly *breathe* more like animals.'

5. 'There is a certain substance in the air we breathe called carbon, which the leaf seizes by a number of tiny lips on its under surface, and out of that it makes the biggest tree that grows in the forest.'

6. 'I want you to notice that the food of a plant is entirely derived from the inorganic or dead world around us.'

7. 'When two elements or more are joined together they make what is called a COMPOUND. Water then is a compound made up of many elements.'

8. 'The sap or juice of plants flowing through the vascular tissue has a great deal of work to do. It takes to every part of a plant the food it needs. Plants can only take liquid food, and sap has the power of turning most of the inorganic substances taken from the earth into a liquid form.'

9. 'The sap of plants is made up of water and carbon.'

10. 'They (the leaves) can change the air which is not fit for the plant's digestion into air which feeds it, but they can do this only in the light of day.'

APPENDIX B

THE MICROSCOPE

By aid of the microscope objects so small that they cannot be properly seen by the naked eye are enlarged and many objects otherwise altogether invisible come into view. Owing to the magnification effected by this instrument minute details that otherwise would be quite unknown can be clearly seen and easily drawn and described.

Parts of the Microscope.

The essential part of the microscope is a tube with a magnifying glass (called the object-glass or *objective*) screwed in at the lower end and another magnifying glass (called the *eye-piece*) slipped in at the top. The tube is kept in position by a *stand* from which projects the *stage* for support of the slide to be examined. Another important accessory is the *mirror* below the stage, from which a beam of light may be directed up through the slide, the object-glass, and the eye-piece. Finally, there are the *adjustments* for lowering or raising the tube.

Examination of Object.

Considerable practice and skill are required before sections of stems or leaves can be satisfactorily cut and permanently mounted. A beginning should therefore be made with objects that require very little preparation. In all cases we require *slides* and *cover-glasses*. The former are neatly-cut pieces of glass measuring 3″ × 1″, and the latter are very thin circles of glass with a diameter of $\frac{7}{8}''$ or less. Both slides and covers should be perfectly clean.

Examination of Starch Granules.

Scrape lightly a cut surface of potato and transfer a very small quantity of the white liquid got in this way to the middle of a slide. By means of a pipette or a glass rod a little water is added. Now take a cover-glass and let it first come in contact with the slide at one point only and then lower it gradually till it is completely in contact with the liquid below it. If the right amount of water was put on it will make a complete layer between the cover and the slide, but not spread beyond the circumference of the former. Now place the slide on the stage, move the mirror till the light strikes the mounted material, and, by means of the wheel at the side of the stand, lower the tube and at the same time keep the eye at the eye-piece and the object will presently come into clear focus. After looking at the granules raise the tube, screw out the objective (which should be one of a lower power), and screw in the higher power. Again lower the tube, this time with greater care, as it will have to come much closer to the slide before the grains are seen. When the focus has been got use the fine adjustment at the back of the stand and by very careful movements you will be able to get still sharper definition.

Write a description of starch granules, including information on the following points:

1. (*a*) The relative size of the granules (are they all the same size?).

(*b*) Their shape and colour.

(*c*) Markings on the surface.

2. Alongside of your written description make a circle with a radius of about an inch and within this draw several granules, representing as many varieties of size and outline as possible. The granules may be drawn the size they appear to be or a multiple of that.

3. Determine the actual size of one or more granules. This can be done in two ways.

(*a*) If the joint magnifying power of eye-piece and objective is known, judge the apparent size of the object and divide by the magnifying power. For example, if to the eye the breadth of the object appears to be $\frac{1}{4}''$, and if the magnifying power is 500 diameters, then the actual breadth is $\frac{1}{2000}$ of an inch.

(*b*) Move the slide till a large granule is brought to the middle of the field of view. Take a fine-pointed instrument, dip it in indian ink, and on the eye-piece make two very small dots, one at each end of the granule. Now raise the tube and remove the slide, putting in its place a stage micrometer. Carefully lower the tube till the lines on the micrometer come into sharp view. These lines are $\frac{1}{1000}''$ apart. Note how many spaces the dots are apart. Allow $\frac{1}{1000}''$ for each interlineal space.

4. Replace original slide on the stage and put a drop of iodine solution quite close to the cover-glass. Hold a small piece of blotting-paper at the opposite side of it in order to absorb some water from under the cover. As this is done, the iodine solution will be drawn in. See what happens. If the same result comes when material from other sources than the potato is similarly examined, what would it prove?

5. Examine in the same way some of the following: Flour, rice, peas, turnip (soaked when necessary).

(*a*) Settle whether starch is present or not.

(*b*) Note whether the granules are similar in shape to those of the potato.

Examination of Epiderm of Leaf for Stomata.

Take any soft leaf of medium thickness and by cross-tearing detach from it a piece of the transparent skin.

(*a*) By touching and stretching this, by laying it out flat and leaving it to dry, by laying it on print, &c., various qualities may be discovered. Write a few sentences describing them.

(*b*) Mount a small piece of the skin and examine under the microscope. If it was taken from the lower surface of the leaf it ought to show the breathing-pores or stomata through which an exchange of gases is effected between the inside of the leaf and the outside air.

A stoma may be easily recognized, as it consists of an elliptical opening, which probably may appear dark, bounded by two curving sausage-shaped cells with green contents. The last-mentioned detail distinguishes them from the surrounding tissue, which is colourless.

1. Make a drawing and write a description of a stoma.

2. Make a small circle of ink dots on the eye-piece and count how many stomata are included within it. With the stage micrometer find the diameter of the circle, then work out its area, and, having further found the area of the leaf from which the piece of skin was taken, calculate:

(*a*) The total number of stomata on the surface of the leaf.

(*b*) The number per square inch.

Flesh of Apple.

Scrape cut surface of an apple, and mount some of the scraped material in water. Single round objects may be seen as well as others still aggregated. These single bodies are vegetable cells, being the structural units out of which all plant-tissues are built up.

1. How do they agree with, and how do they differ from, starch granules?
2. Are their walls thick or thin?
3. What is their general shape?
4. Describe the contents of each. (The cell-wall is transparent and you see through it into the interior cell.)
5. Write your answers to the above in the form of a short description and add any further details you may observe, illustrating your answers by a drawing.

Examination of Vessels.

Take some of the stringy substance to be found in the stalks of rhubarb or other leaves. It may be got also from soft green stems. Put one or two of the shreds in a watch-glass and tease them—that is, pull them apart into finer components by the use of a couple of mounted needles. Mount some of the finest threads as usual and examine. Look this time not for round bodies, but for long narrow ones. Some of them may easily be detected by the character of the screw-like thickening that runs up their inside. These long narrow tubes are called vessels, and by them the sap ascends to the leaves. A vessel is really a line of modified cells; they have grown to the length and are open at their ends, so that their through communication is established.

1. Make a drawing.
2. Note briefly some of the chief facts.
3. Measure the width of a vessel.

Cautions.

1. Only soft and clean cloths (silk or chamois) must be used to remove dust or other material from the lenses of the microscope.

2. The instrument should not be placed too near the edge or corner of the table.

3. Examine with the low power before using a high one.

4. Avoid sunshine. A north window is best for microscopic work.

5. Special care must be taken not to bring high powers into contact with the slide.

Magnification.

The object-glasses are classified according to their focus, 1″, ½″, ⅓″, ⅙″, 1/12″, and so on, 1″ being the lowest of those named. A microscope is not complete without at least two objectives, say ⅔″ and ⅙″. Two eye-pieces are also usually provided, one of them magnifying more than the other. If an eye-piece magnifying 5 times is used with an objective magnifying 10 times, the total magnification is 50. A card ought to be supplied along with the microscope showing the various magnifications obtainable. Notice that magnification is expressed in linear terms, not in terms of area. If we say that an object is magnified 10 times (that is, 10 diameters) we mean it is 10 times longer and 10 times broader than in the actual. In terms of the area it would be 100 times bigger; and so an object magnified 400 diameters has its area increased 160,000 times.

THE BAROMETER

The barometer does not directly tell what the weather is or is going to be. What it does tell is the weight of the atmosphere at the place of observation. From this information conclusions may be drawn with regard to the weather.

A barometer of a simple kind is more easily made than a thermometer. Take a straight tube about 33 inches long and closed at one end. Fill it with mercury. Close the mouth of it firmly with finger or thumb and invert it with the lower end dipping into a basin of mercury. Now remove your finger or thumb and fix the tube in the erect position by help of a metal stand. The mercury no longer fills the whole tube, but if a paper scale be fixed to the tube and readings taken for several days, it will be found that sometimes the mercury reaches farther up the tube than at others, though it never rises to the top.

Two questions present themselves:

1. Why does the mercury remain in the tube?

2. Why does the column not always rise to he same height?

Its own weight would naturally bring the mercury in the tube down to the level of the mercury in the basin. What prevents this from happening? Certainly not the pressure of the mercury in the basin, for this is sufficient to balance and therefore keep in place only enough of the liquid to fill the submerged portions of the tube. Evidently some other force is at work, and this is just the pressure of the atmosphere acting on the exposed surface in the basin.

We note then that—

1. The weight of the column in the tube is a measure of the pressure of the atmosphere;

2. Variations in the height of the column indicate corre-

sponding variations in the pressure of the atmosphere at the place of observation.

Notice that the height of the column must be measured, not from a fixed point at the foot of the tube, but from the level of the mercury in the basin. Where a scale is attached its zero must be exactly at that level.

1. Take readings two or three times daily for a fortnight and plot them against time.

2. If the paper scale is fixed to begin at a certain level, and if the mercury rises, the scale will no longer give the correct reading, for if there is more mercury in the tube there will be less in the basin. Suggest two ways of getting over the difficulty.

3. What else than extra atmospheric pressure might lengthen the column of mercury?

4. The average height of the mercury is nearly 30″. Express this in millimetres.

5. Taking mercury as 13·5 times as heavy as water, find the height of a column of the latter liquid which would be equal to 30″ of mercury and which therefore the atmosphere would be able to support.

6. The height of the mercury diminishes as you rise above sea-level, for there the amount of atmosphere above the barometer is less. If at the top of a cliff 90 feet high the barometer is 0·1 inch lower than at sea-level, you would naturally expect that at 900 feet there would be a fall of 1 inch and at 9,000 feet you would expect a fall of 10 inches—that is, you would expect a barometer on an average to register 20 inches at the top of a mountain 9,000 feet high. If it registers less than this, what conclusion do you draw?

In all experiments where the weight of the air may influence the results, barometric readings should be taken simultaneously with the other readings if complete accuracy is desired. According to the new method of expressing it barometric pressure is now given in millibars, 1,000 millibars being equivalent to 29·53 inches of mercury.

CHEMICAL BALANCE

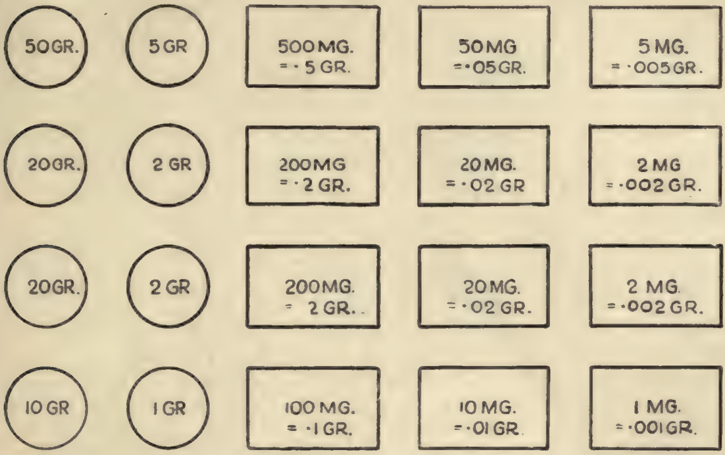
This resembles in general principles ordinary scales and weights used in shops. It is, however, much more carefully made and has various special arrangements for securing delicacy and accuracy.

Parts of the Balance.

From the base-board rises an erect support or pillar with a knife-edge on the top of it on which swings the beam. This has two knife-edges, one at the end of each arm, and from these hang the pan-holders supporting the loose scale-pans. These are the main parts. The other parts will be mentioned as we describe how to get the balance ready for use.

Place the balance on a firm flat table and judge from the plumb-line whether the pillar is quite perpendicular or not. If necessary, work the screws under the base-board till the plumb-line comes to the required position. Now gently raise the handle in front of the base-board and bring it over to the right hand. This will bring the beam down to the knife-edge and put it in action. See if the empty scale-pans balance each other. If one is lighter bring the beam back to rest and twist the small screw at the same end of the beam till it is moved out from the pillar. In its new position it will tend to increase the weight of the arm. Try again if the two arms are in equilibrium. Further adjustment may be made by bringing the other small screw nearer to the pillar. If this falls one or two fragments of paper may be added to the lighter scale-pan.

When equilibrium has been established, bring the balance to rest and place the object to be weighed on the left-hand scale-pan. Then open the box of weights and with the forceps it contains lift on to the right-hand scale-pan what you think might be the proper weight. Bring the beam to the knife-edge and see if the weight is sufficient. If not, more must be added till the weights and the object balance each other. Then sum up the weights and the operation is complete.



With the above any weight can be determined from 1 milligramme to 111·11 grammes.

Notice that on the right arm of the beam (which will be seen to be divided into 10 equal parts numbered outwards from the pillar) there is a small movable object. If this object called the *rider*, weighs 10 mg. it will be equivalent to that weight on the scale-pan if placed at the outside end of the arm, but for every division it is put nearer the middle it loses one-tenth of its weight. By using the rider differences of 1 to 10 milligrammes can be weighed without the use of the smaller weights.

N.B.—1. Finer balances should be kept in glass cases with sliding doors and should never be moved to any other position. They must be used where they are kept.

2. When not in use the balance should be off the swing.

3. The scale-pans should be thoroughly clean.

4. It is most important to be able to use the balance and to weigh accurately. Special care should be taken to acquire the necessary skill.

Some objects may be so light that when placed in the scale-pan they produce absolutely no effect. Other objects may weigh so little that a slight actual error may in proportion to the weight of the object be a large one. Suppose you are using an ordinary chemical balance for weighing a small seed and find it to weigh 1 milligramme when it really only weighs half that amount. The error may appear small—only half a milligramme—but consider that it would not be accounted a small error to give the weight of a 1 lb. object as 2 lb., and yet the error in the two cases would be in the same proportion to the actual. In cases like this an easy and satisfactory way is to weigh not one seed but a large number and then find the average weight of one seed by dividing by that number. Here is an example. It was desired to find the weight of a seed of shepherd's purse. It was too small to weigh singly and so a counted number of these seeds (370) was placed on the scale-pan and found to weigh 55 milligrammes. Dividing by 370 we found that the weight of each was ·148 milligramme (that is between $\frac{1}{6}$ and $\frac{1}{7}$ of a milligramme). In a case like this the error is distributed and the share of it that goes to each individual object is negligible. In the above example, if the correct weight was 50 mg. how much heavier than it actually was did each seed appear to be? What fraction of the real weight was the error?

Weigh:

1. A halfpenny.
2. A sixpence.
3. A threepenny bit.

Find the weight of:

1. A postage stamp.
2. One-tenth of a square inch of tissue-paper.

THE THERMOMETER

A thermometer is a tube of narrow bore ending in a bulb at one end and simply closed at the other. Inside there is a supply of mercury which fills the bulb and runs up into the tube over a longer or shorter distance according to the temperature. The remainder of the tube is free or very nearly free of air.

A thermometer indicates the temperature by degrees marked on the glass or on an attached scale. Two kinds of thermometers are in use in this country, the Centigrade, which is to be preferred for scientific work, and the Fahrenheit. The latter owes its name to Gabriel Daniel Fahrenheit, who was the first to make (about 1714) a thermometer of this kind. It was a great improvement on what was used before. The Centigrade came into use later.

In the Fahrenheit thermometer the freezing-point is 32 and the boiling-point 212. In Centigrade these two points are respectively 0 and 100.

1. What is the use of the bulb at the end of the thermometer?

2. Why is care taken to exclude air from the thermometer tube?

3. On what three accounts would water be an unsatisfactory substitute for the mercury?

Exercises in taking Readings.

1. Take two glass jars of equal size and fill them with hot water, which should be of the same temperature in each case. One of the jars should be placed inside another one a size or two larger so that there will be a jacket of warm air round the inner one. Place a thermometer in each jar of hot water and take readings at frequent intervals in order to ascertain

the rate of cooling in each case. Plot a graph of each set of readings against time.

2. Fix a thermometer near a window never exposed to the direct rays of the sun (or elsewhere if more convenient) and make a record of readings taken three or four times daily for a week or more. Perhaps it might be possible, if readings were taken daily some hours before midday and the same number of hours after, to settle whether afternoon or forenoon is usually the warmer. The readings will require to be continued for some time, say a fortnight or three weeks.

Special Temperatures.

Water.		
Boiling-point	100°	Centigrade.
Freezing-point	0°	,,
Maximum density	4°	,,
Air.		
Average temperature of living-room in round numbers	15°	,,
Liquefaction point	−192°	,,
Greatest arctic cold	−61·7°	,,
Mercury.		
Boiling-point	350°	,,
Freezing-point	−40°	,,
Blood-heat.		
In man	37°	,,
In birds	Up to about 45°	,,

APPENDIX C

WEIGHTS AND MEASURES

Length.

1″ = 25 millimetres (25·399).	1 millimetre = $\frac{1}{25}''$ (·03937).
1 yard = ·9 metre (·91439).	1 metre (1000 millimetres) = 39·37″.

Area.

1 sq. inch = 6·5 sq. centimetres (6·45148).	1 sq. centimetre (100 sq. millimetres) = ·155 sq. inch.

Volume and capacity.

1 cubic inch = 16·39 c.c.	1 cubic centimetre = ·06102 cubic inch.
1 fluid ounce (1·73 cubic inches) = 28·4 c.c.	1 cubic centimetre = ·035 fluid ounce.
1 pint (34·65 cubic inches or 20 oz.) = 568 c.c. = over $\frac{1}{2}$ litre.	1 litre = 1·76 pints.
1 gallon (160 oz.) = 277·274 cubic inches = 4·5 litres (4·54).	1 litre = ·22 gallon.

Weight.

1 grain = ·0648 gramme.	1 milligramme = ·01543 grain.
1 oz. avoirdupois (437·5 grains) = 28·35 grammes.	1 gramme = 15·432 grains. = $\frac{1}{28}$ oz.
1 lb. avoirdupois (7000 grains) = ·45359 kilogramme.	1 kilogramme = 2·2 lb.

All metric weights and measures are based upon the unit of length. The table of length measurement is as follows:

10 millimetres = 1 centimetre.
10 centimetres = 1 decimetre.
10 decimetres = 1 metre.
10 metres = 1 decametre.
10 decametres = 1 hectometre.
10 hectometres = 1 kilometre.

A micron is $\frac{1}{1000}$ part of a millimetre and is indicated by the Greek letter μ.

The measurement of length can be made in the laboratory when no special accuracy is required, by the ordinary 12″ ruler. Paper scales will also be found most convenient. Dealers are not often able to supply them, but when a large number is required recourse may be had to a printer. They should be a metre in length and should show inches and tenths along one margin and millimetres along the other, numbered at the tens.

Unit of Weight. This is the gramme, which is the weight of a cubic centimetre of distilled water at 4° Centigrade.

AREAS AND VOLUMES

Area of triangle.

Multiply the base by the perpendicular height and divide by 2.

Area of rectangle.

Multiply length by breadth.

Circumference of circle.

Multiply the diameter by the fraction $\frac{22}{7}$ (3·14).

The formula for the operation is $2\pi r$.

Area of circle.

Use the formula πr^2, that is, multiply the square of the radius by $\frac{22}{7}$.

Volume of sphere.

This can be found by the formula $\frac{4}{3}\pi r^3$.

Volume of cylinder.

Multiply area of end by the length (height).

Volume of cone.

Multiply the area of the base by half the height.

Exercises.

I. (*a*) Calculate volume of—

1. Cylindrical jar.
2. Conical flask.
3. Flask (sphere + cylinder).

(*b*) Convert the answer into metric volume (cubic centimetres).

(*c*) Fill each of the above vessels with water and by help of a graduated measure find how many c.c. each holds. Compare the amounts with those arrived at under *b*.

II. Draw a triangle of fair size (say with sides from 2″ to 3″ in length). Find its area, first by formula, second by squared paper.

III. Use a metal gauge to find the bore of a fairly narrow tube (3 to 4 millimetres) and then calculate how much water would be required to fill a foot of it. Give the answer in c.c. Then find by trial the actual amount.

IV. Describe on a piece of cardboard a circle with a radius of 2″ or 3″. Apply the formula to find out the length of the circumference. Then cut out the circle carefully. Make a dot with ink anywhere on the circumference. Place the plane of the circle at right angles to the plane of the table with the dot touching the table. Mark this place on the table. Now roll the circle along till the dot comes back to the table. Mark this second position and measure the distance between it and the first. That will give the length of the circumference.

Estimation of Area.

1. In order to find the area of a leaf-surface, lay the leaf on a piece of squared paper and carefully trace its outline thereon. By counting the number of small squares included within this line, the area of the leaf can be pretty accurately got. When small squares are cut by the outline the portion to the inside is counted as a whole if it is greater than half. If it is exactly half it counts such, and if it is less than that it is not counted at all. When the sum of small squares has in this way been got, divide by 100 and the answer is the number of square inches on the surface of the given leaf.

2. One or two other methods may also be employed. Take again the squared paper and cut out

(1) A piece the size of the leaf, and

(2) A rectangular portion including several large squares, say six.

Weigh each of these pieces. If the paper is uniform in thickness the area of each piece will be in proportion to its weight. As both weights and one area are known, it is very easy to find the other.

3. A similar method may be sometimes adopted without the intervention of squared paper. Weigh the whole leaf without any of its stalk. Cut out a square of the leaf and weigh it. By proportion the area of the whole is arrived at. This method is of no use where the midrib is thick.

4. When the area of all the leaves on a plant or single shoot is wanted, there is a rough and ready method which often gives an estimate near enough for practical purposes. It is at least simple and rapid. Pull off all the leaves and fit them together so as to form a rectangular figure on the table. Then multiply the length of this by the breadth and the thing is done. One or two of the leaves can be cut up and the fragments fitted into blanks.

5. If a leaf has a geometrical shape its area can be calculated without any squared paper and without any weighing. If it is circular, measure the radius and apply the formula πr^2.

(1) Choose a suitable kind of leaf, estimate its area by as many methods as possible and compare results.

(2) Suggest any other method than 4 for dealing with a large number of leaves, assuming that it would take too long to take the area of each separately.

(3) Four circular leaves have diameters of 4, 6, 8, and 10 inches respectively; find the total area.

(4) How would you find the surface area of an inch or two of smooth, round stem?

(5) In what circumstances would it be possible to find the area of a large number of leaves very easily and directly after estimating by squared paper the area of one?

(6) Suppose a tree with a million leaves spreads its branches in all directions to an average distance of 15 feet from the stem, compare the area of soil shaded by the tree with the total area of its leaves, allowing 10 square inches for each leaf.

(7) Water evaporates more quickly (sometimes five times) from a water-surface than from a leaf-surface, yet trees are said to help in keeping the air damp. Would not a pond equal in area to the ground shaded by the tree be more effective in this respect than such a tree as is supposed above? If not, why not?

APPENDIX D

GRAPHS

Many kinds of experimental results are very easily and usefully expressed in the form of graphs. For this to be possible there must be at least two separate varying quantities which can be plotted against each other. One of these is generally time, and the other might be length or breadth in millimetres (or inches), or volume (in c.c.), or temperature (in degrees). A very simple example will show what is meant. Suppose that water is being pulled along a narrow tube by a transpiring twig attached at one end and that by observation every hour we get the readings as follows:

Hour.	*Distance of water from open end of tube.*
10	20
11	80
12	140
1	200
2	260
3	320
4	380

For making the graph we use paper which is ruled off by thicker lines into squares measuring an inch on the side. By fainter lines each square inch is subdivided into 100 smaller squares, each measuring 0·1″ on the side and having, of course, an area of 0·01 of a square inch. Suppose the particular piece of paper at your disposal has seven large squares along one side and nine along the other. Make the shorter side the foot and place the paper on the table with this edge next you. Two quantities, time and distance or length, have to be marked off and the lowest left-hand angle made by the darker lines is chosen as the starting-point. One quantity is measured from this point towards the right along the base line, and the other from the same point towards the top of the paper along the vertical line. Before beginning the actual marking off, we must settle the scales. Take time first. It is usual to mark it along the base of the line. There we have seven squares and the total period to be represented is six hours. It will be simplest to neglect the seventh square and then we shall have a square for each hour. So we put 10 at the point of origin and 11 an inch to the right, and so on. In the other direction we lay off the millimetre scale. Here there are 9 larger squares and therefore 90 smaller ones. It would be very convenient to let each 0·1″ represent a millimetre, but as we have a total of 380 millimetres and only 90 small squares at the side, it is easy to see that our scale is more than four times too large. Let us therefore reduce it to one-fifth of this, then the side of each small square will represent not one but five millimetres, and up the side there will be room for 450, which is more than is needed. The next step is to find points on the paper for each observation. The first is at 10 o'clock and therefore no distance along the line, but as the reading was 20 millimetres we must go four small squares up the side and put a dot there. The second was at 11 o'clock (that is 1″ along the base line) and the reading was 80 millimetres, which means 80 divided by 5, that is 16 small squares up the side. Our second dot will be made where the perpendicular from this point intersects the perpendicular from 11 o'clock, and so on with the other hours and readings. When all the dots (seven in number) have been put in, join these up. The line thus formed is the graph and the process gone through is called plotting the graph.

Exercises.

Make a graph of the following readings:

Hour.	*Reading in Millimetres.*
10	0
10.18	6
11.6	22
11.30	30
12.24	40
1	60
2.6	82
3	100
4.36	132
5	140

In this case we begin at 0, so 10 o'clock and the first reading are represented by a dot which is neither along nor up from the starting-point. Notice that the readings are not all taken at the end of a full hour. A point must be found for 10.18 somewhere between 10 and 11, and so on. Find scale for the millimetres. Up the side there are 90 small squares and 140 millimetres have to be got in. Evidently a millimetre cannot get as much as $\frac{1}{10}''$.

When the movement is rapid, readings are taken much more frequently. Make a graph to cover an hour when the readings are taken every minute and show a rise of 5 millimetres each time. Settle the scales and start at 0. The object of plotting a graph is to show lines (straight or curved as the case may be), and the dots for the readings are put in that the lines may be indicated. In the present example, if each reading were indicated by a dot on the squared paper, there would be 61 dots. It is not, however, necessary to make all these. Just put in the first and the last and five or six in between at intervals. This will be sufficient to give the lie of the line.

The following series of readings was taken from an experiment in which a large fresh shoot of elder with from 20 to 30 leaves (total area about 540 square inches) was attached to a horizontal glass tube of 2 millimetre bore. The readings were taken every minute:

210, 230, 255, 272, 293, 318, 335, 357, 377, 398, 419, 440, 459, 479, 497, 517, 536, 555, 575, 594, 612, 631, 650, 669, 688, 706, 725, 744, 762, 780, 799, 818, 836, 855, 873, 892, 911, 929, 948, 957, 985, 1004 (two readings omitted), 1060, 1079, 1098, 1119, 1138, 1157, 1177, 1196, 1215.

To show the effect of a damp atmosphere on the rate of transpiration, a transpiring twig was for part of the duration of experiment kept under a bell-jar, while for the other part the air of the room was allowed free access. Plot the readings and after the graph is made settle whether the bell-jar covered the twig during the earlier or during the latter part of the experiment, and also which of the two periods was the longer.

Hour.	*Reading in Millimetres.*
10.58	105
11.1	110
11.8	122
11.22	136
11.31	143
11.46	154
11.51½	160
12.5	191·5
12.15	219
12.24	245
12.35	275
12.41½	291
1.25	430

An experiment was made to show the effect of temperature on the rate of transpiration. A transpiring twig was placed in a bell-jar under which there was also some calcium chloride to keep the air dry. After readings had been taken for some time, showing the rate at which water was pulled along the narrow tube attached to the twig, a vessel containing heated sand was introduced. This caused a considerable rise in temperature inside the jar.

Time.	*Readings in Millimetres.*	*Temperature, Centigrade.*
9.42	36	14°
9·45	44	
9.50	52	
10.10	78	
10.20	92	17·5°
10.36	111	15·5°
11.2	140	
11.36	168	
12.4	214	16°
12.14	226	
12.22	237	17·5°
12.28	247	28°
12.36	298	37°
12.42	322	35°
12.50	349	32·5°
1.4	384	28°
1.24	425	23°
1.45	459	20°
1.49	465	20°

1. Plot a graph of the above.

2. About what time was the hot sand put in?

3. What was the effect of it?

4. Why is the rate of absorption reduced towards the end?

Pieces of rhubarb leaf, one square and one rectangular, were dried in drying chamber, and the loss of weight is shown in the results given below:

Put in at	*Taken out at*	*Minutes in.*	*Rectangular Piece.*		*Triangular Piece.*	
			Weight.	*Decrease.*	*Weight.*	*Decrease.*
			1·56		2·75	
11.32	11.42	10	1·19	0·37	2·11	0·64
11.46	11.56		0·92	0·27	1·74	0·37
12.3	12.13		0·66	0·26	1·34	0·47
12.17	12.27		0·44	0·22	0·97	0·37
12.32	12.42		0·305	0·135	0·67	0·30
12.50	1		0·16	0·146	0·37	0·30
1.6	1.16		0·155	0·005	0·25	0·12
1.21	1.31		0·155	0·0	0·25	0·0

1. Plot each series of decreasing weights against time, leaving out of account the time occupied in weighing.

2. Where do the curves show—
   (*a*) Rapid loss of water?
   (*b*) Medium rate of loss?
   (*c*) Slower loss?
   (*d*) No loss?

3. Account for the different rates.

4. Point out and explain any difference between the two curves.

Measurements were made of the growth in length and in breadth of one of the earlier leaves of a sunflower seedling.

Date.	*Length.*	*Breadth.*
17th May	5	2·5
18th ,,	5	2·5
21st ,,	8	4
25th ,,	20	10
28th ,,	30	15
31st ,,	34	17
4th June	37	19
th ,,	45	25
11th ,,	65	40
13th ,,	66	41
18th ,,	70	43
21st ,,	70	46

The measurements are in millimetres.

1. Plot a graph of each (length and breadth) on the same paper against time.

2. What change has come over the shape of the leaflet in the course of its growth?

3. The rate of increase is slow at several places. Point out two of these where the slowing is probably to be accounted for by the tendency of the leaflet to grow more rapidly at one time than at others?

4. Point out also one place in the curves where decrease in rate might very probably be due to cold or dull weather. Give reasons for not attributing the slow growth here to the nature of the leaf itself.

With every set of graphs there should be:

(*a*) Title showing subject dealt with.

(*b*) Note of scales.

(*c*) Statement of general fact or facts emphasized.

(*d*) Separate description for each graph.

1. The curves should be made in fine lines either continuous or interrupted.

2. Angles in these lines should where possible be avoided.

3. Where there are several curves on the same piece of paper, differentiate them by colour or by the character of the line itself.

4. The original dots on which the line is constructed should not be obliterated.

APPENDIX E

CHEMICAL TESTS

A test is an experiment, usually of a simple nature, which enables us to detect the presence of a particular substance, or of a particular kind of substance, or of certain conditions.

1. Iodine is used as a test for starch. If on the addition of iodine solution to the material we are examining a blue or violet colour is produced, we may be sure that starch is present. To prepare iodine solution take a 10 or 20 oz. bottle with glass stopper and put in say a gramme of metallic iodine, together with a similar quantity of potassium iodide, and fill up with water. A rich brown-coloured solution will immediately be formed. For use take a small quantity of this and add water till it is a pale colour.

2. Lime-water is used to test for carbon dioxide. It becomes milky in the presence of this gas. Lime-water may be easily prepared. Put some calcium hydrate $Ca(OH)_2$ in a bottle and shake it up with water. Only a little of the white powder will dissolve. The rest sinks to the bottom. Pour off and filter some of the clear liquid and it is ready for use. The bottle containing it must be kept carefully stoppered, otherwise the carbon dioxide of the air will affect it. The milkiness produced when lime-water and carbon dioxide are brought together is due to the formation of carbonate of lime, whose formula ($CaCO_3$) shows that it is a compound of CaO (part of the calcium hydrate) and carbon dioxide.

Baryta-water. This is made from barium hydroxide in the same way as lime-water from calcium hydroxide. It is used as a test for carbon dioxide, and barium carbonate $BaCO_3$ is formed when this gas is mixed with the water.

Litmus-paper. This is of two colours, red and blue, and is used to show whether any given liquid is of an acid, alkaline, or neutral character. In the presence of an acid, blue litmus turns red, and in the presence of an alkali, red litmus turns blue. In a neutral solution (that is, one that is neither acid nor alkaline) neither red nor blue litmus changes colour. It must be noted that when blue litmus turns red it is not to be concluded that the liquid is all acid or that only one acid is present. All that we know is that it is of an acid tendency. A drop or two of a strong acid can impart acidity to a large bulk of water. Similarly, alkalies, even when present in minute quantities, give an alkaline reaction.

Various Practical Hints.

Filtering.

Fold the circular filter-paper along one diameter and then fold it again along the middle radius. Open up the folds so that there is a single fold at one side and three at the other. Now place it in the glass funnel, which has to be supported in the neck of a conical flask. Pour on to the filter-paper the liquid to be filtered. This operation is used to separate solid particles from a liquid. What goes through is called the *filtrate.*

Cutting Glass Tubing.

With a three-sided file make a distinct scratch across the tube and place your thumbs close together on the upper side with the scratch between them. With the rest of the hand below press upwards and the tube will break across. Hold the new ends in a bunsen flame to get the sharp edges rounded.

Bending Glass Tubing.

Hold the tube by both ends and let the flame of a fish-tail burner heat the place where the bend is desired. Ensure equal heating over an inch or two of the tube by moving it a little from side to side through the breadth of the flame and also by turning it round. When the glass is fluid move it away from the flame and make the bend by gradually bringing the ends up.

How to fit a Twig into a Rubber Stopper.

Pass a cork-borer up through the hole in the stopper. Put the end of the twig down into the cork-borer and, keeping the stopper and twig in their relative positions, withdraw the borer, when the rubber ought to grip the twig. If the twig is loose a stopper with a smaller hole must be taken or a larger twig substituted. On the other hand, if the twig is too big to slip into the cork-borer, then take a borer one size larger and get it down over the first bore, which then may be removed. Thirdly, take a borer one size larger still and pass it up over the second, which in turn is taken out. Now get the twig into the third borer and proceed as described above.

Putting a Fine Point on a Tube.

Hold the tube in the flame and when soft stretch the heated portion. When the tube is cool it can be broken at the finest part. This will give two tubes each with a fine point.

APPENDIX F

NOTES ON GASES

Name.	*Symbol.*	*Formula.*	*Atomic Weight.*	**Density.*	**Weight of Litre.*	*Date of discovery or first accurate description.*
Hydrogen	H	H_2	1	0·0693	0·0896	1766
Nitrogen	N	N_2	14	0·971	1·256	1772
Oxygen	O	O_2	16	1·105	1·430	1774
Carbon dioxide		CO_2	22	1·53	1·966	1756

* At temperature of 0° C. and at a pressure of 760 mm.

Hydrogen.

This gas was first accurately described by Cavendish in 1766. It has an atomic weight of one and is the lightest body known. It burns, but does not support combustion. A considerable percentage of ordinary coal gas consists of hydrogen. Hydrogen may be readily prepared by pouring dilute sulphuric acid on zinc, but as it forms an explosive mixture with air or with oxygen, special precautions must be taken in collecting and testing it.

Nitrogen.

This gas was discovered by Rutherford, an Edinburgh professor. Like oxygen, it is colourless, tasteless, and inodorous, and is somewhat lighter than air. The following facts are important:

1. Nitrogen forms about four-fifths of the air by volume.
2. In the free state it does not readily combine with other bodies, neither itself burning nor supporting combustion.
3. Nitrogen in compound form is found in the body of every living plant and animal.
4. Plants obtain their supplies chiefly by the root in the form of nitrates.

Oxygen.

This gas was discovered by Priestley in 1774 and also by the Swedish chemist Scheele two or three years earlier. By the former it was called dephlogisticated air and by the latter empyreal air. A little later it was called vital air, but it was the famous French chemist Lavoisier who gave it the name by which it is still known.

Oxygen has neither taste, odour, nor colour. From its density, as given above, we see that it is slightly heavier than ordinary air. It was first liquefied in 1877.

Note the following facts about this most important gas:

1. It is the most abundant element in nature.

2. It is largely present in combination with other elements in the solid crust of the earth, combined with hydrogen in the liquid water that in part covers the earth, and in the free state in the gaseous atmosphere that surrounds the whole world. Thus it helps to form earth and sea and sky.

3. Without it neither ordinary combustion (such as we have in fires) nor the breathing of plants and animals could go on at all.

4. It readily unites with other elements forming oxides.

With only a few will it not combine.

1. Leaving out of account the other constituents of air and supposing that four-fifths of it by volume is nitrogen and one-fifth oxygen, find their respective proportions by weight.

2. Supposing a man in breathing uses up 10,000 grains (say 650 grammes) of oxygen in 24 hours, find the volume of air represented by this. (1 litre of air weighs 1·293 grammes.)

3. For healthy breathing a man ought to have at his disposal not less than 800 cubic feet of well ventilated space. If the answer to the last question shows a less amount than this, explain why the larger amount is required. (1 litre = 61·0270 cubic inches—that is, 28 litres are roughly equal to 1 cubic foot.)

4. Suppose a plant has a total leaf-surface sufficient to liberate 0·3 litre of oxygen in an hour of sunlight, how many such plants would there require to be in a room to make up for the oxygen used up by the breathing of one man?

Carbon Dioxide.

This gas, also known as carbonic acid, carbon anhydride, fixed air, and choke-damp, is uniformly present in the atmosphere, of which, however, it forms a very insignificant fraction, there being generally present about three parts of the gas to 10,000 of air. Its importance is altogether out of proportion to its amount, for it occurs in the breath of plants and all animals, and also under other conditions in the mineral kingdom. It ought also to be specially noted that it is from the supplies of this gas in the air that plants obtain the carbon without which both the vegetable and animal kingdom would perish.

Carbon dioxide was first noted as something different from air by Van Helmont (1577–1644), but Dr. Joseph Black, a Glasgow, and afterwards an Edinburgh, professor, was the first to connect it with the carbonates. He published his discovery of it in 1756, giving it the name of fixed air. This name was changed to carbonic acid by Lavoisier in 1784, after he had proved it to be an oxide of carbon.

Carbon dioxide has neither colour nor smell, but it has a slightly acid taste and is heavier than air. Its formula is CO_2, which means that its molecule consists of two atoms of oxygen chemically combined with one of carbon.

Carbon dioxide becomes a liquid at 0° Centigrade under a pressure of about 35 atmospheres. If a quantity of the liquid is allowed to evaporate quickly, so great cold is produced that some of the liquid turns into a snow-white solid.

From the numbers given above we can deduce that of any given weight of carbon dioxide three-elevenths is due to the carbon in it and the remaining eight-elevenths to the oxygen.

1. How much heavier is carbon dioxide than air?

2. A room measures 10 feet × 20 feet and is 10 feet high. How many litres of carbon dioxide could it hold and what would be the weight of this amount?

3. How many litres and what weight of carbon dioxide would there be in the above room if filled with ordinary fresh air?

4. It has been calculated that a square metre of leaf-surface

uses up three-tenths of a litre of carbon dioxide every hour of sunlight. How long would the air of the above room (supposing no fresh air whatever were admitted) afford a sufficient supply of carbon dioxide to a plant whose total leaf-surface comes to the above amount? Give the answer in days, allowing ten hours of sunlight to each day.

5. If the leaves of a plant had an area of ten square inches, how many leaves would it require to have to make up a total leaf-surface of one square metre?

6. According to Detmer, 25 lupin seedlings may produce about 18 milligrammes of carbon dioxide in two hours. Suppose they were placed in a room of the size given in question 2, in what time would the quantity of carbon dioxide in that room be doubled if there were no ventilation? What multiple of the original amount of the gas would be added in 24 hours?

7. A full-grown man might breathe out in 24 hours 12,000 grains of carbon dioxide (1 milligramme = ·015432 grain); how soon would he double the carbon dioxide in the room mentioned above, and to what extent would he pollute the air of it in 24 hours?

WATER.

Without studying the physical properties as well as the chemical composition of water it is impossible to understand how plants live. A good deal can be learned by simply observing the familiar process of boiling.

Fill a beaker $\frac{3}{4}$ full of water. Heat it with a bunsen flame and observe what happens. Perhaps the outside of the beaker gets dim (this by the way). Bubbles rise, a white cloud appears above the water, the water decreases in quantity.

1. The bubbles are of two kinds. Distinguish them.

2. Of what are the bubbles that come out later composed? Give reasons for your answer.

3. Where do the bubbles start from?

4. What change comes over them as they rise?

5. Of what is the white cloud composed? It would not be correct to say steam, as steam is invisible.

Some light may be thrown on the nature of some of the bubbles if the following experiment is set up:

Fill a flask (whose capacity has been ascertained) with water and arrange that a tube put firmly into its neck by a rubber stopper and also filled with water, lead to a pneumatic trough. Above its end, which must open under water, place an inverted test-tube also full of water. Now apply heat to the flask and bubbles will rise, pass along the bent tube, and finally collect at the upper part of the test-tube.

1. Do all the bubbles that form in the flask find their way into the test-tube? Do not form a conclusion on this point till the water has been boiling for a few minutes.

2. Compare the volume of the gas collected in the test-tube with the original amount of water in the flask.

3. What gas is it?

Latent heat. This was explained in Chapter VIII.

Repeat the experiment there described and tabulate your results. The following is an example:

1. Weight of calorimeter	54 grammes.
2. Weight of calorimeter plus water .	125 ,,
3. Weight of calorimeter plus water and condensed steam	133 ,,
4. Initial temperature	13° C.
5. Final temperature	70° C.

The above results show—

(*a*) Weight of water originally in calorimeter	71 grammes.
(*b*) Weight of condensed steam . .	8 „
(*c*) Rise in temperature	57° C.

Now in the experiment as carried out there has evidently been a transference of heat from the steam to the water in the calorimeter and to the calorimeter itself. Some of the heat has been imparted to the air surrounding the calorimeter, but this is a small proportion and for the purposes of the experiment we shall assume that the whole of the heat lost by the steam has been absorbed by the water and the calorimeter.

Heat is measured in units called *calories*. A calorie is the amount of heat required to raise one gramme of water through 1° Centigrade, *or* the amount of heat given out when 1 gramme of water cools through 1° C.

First let us consider the absorption of heat by the water. Since to raise 1 gramme of water through 1° C. needs 1 calorie, obviously to raise 71 grammes of water through 57° C. will need

$$71 \times 57 = 4047 \text{ calories.}$$

Some heat, however, has been absorbed by the copper calorimeter. Now copper needs only $\frac{1}{10}$ of a calorie in order to raise 1 gramme of the metal through 1° C. To raise 54 grammes through 57° C. will therefore need

$$\tfrac{1}{10} \times 54 \times 57 = 308 \text{ calories.}$$

The total number of calories absorbed by the calorimeter and water is therefore

$$4047 + 308 = 4355 \text{ calories.}$$

These 4355 calories have been obtained from

(*a*) 8 grammes of steam at 100° C. condensing to water at 100° C.

(*b*) 8 grammes of condensed water cooling from 100° C. to 70° C. The number of calories from this source is

$$8 \times 30 = 240.$$

Hence

8 grammes of steam at 100° C. condensing to water at 100° C. evolve

$$4355 - 240 = 4115 \text{ calories.}$$

Or, 1 gramme of steam at 100° C. condensing to water at 100° C. evolves

$$4115 \div 8 = 514 \text{ calories.}$$

The accepted value for the latent heat of steam is 537 calories. There are, however, several sources of error in the rough experiment described. One has been already indicated. Can you suggest others?

Mix say 10 lb. of ice (temperature 0° Centigrade) with 10 lb. of water at 79° Centigrade or more. Let the ice melt and then take the temperature. It will not be what you might have expected. Explain the result.

1. Why is one more likely to catch cold in a railway carriage with a wet floor than in a dry one?

2. At certain seasons a west wind blows over the Rocky Mountains and gives rain. As it comes down from the mountains it is a warmer wind than when it went up and rapidly melts the snow on the prairies to the east of the mountains. Where does the wind get its heat?

3. Why should a thaw tend to become a frost again?

ACIDS

Name.	*Formula.*	*Common Name.*	*Related Class of Salts.*
Nitric	HNO_3	Aqua fortis	Nitrates.
Sulphuric	H_2SO_4	Oil of vitriol	Sulphates.
Hydrochloric	HCl	Muriatic acid	Chlorides.
Acetic	$C_2H_4O_2$	Vinegar	Acetates.
Carbonic	H_2CO_3	Choke-damp	Carbonates

Sulphuric acid and carbonic acid differ from the others in having no smell. Acids in general act energetically and are often used in the laboratory to dissolve substances upon which weaker solvents such as water have no effect. Concentrated acids must be used with the greatest care. Otherwise accidents such as severe burns may be occasioned.

EXAMPLES OF COMMON SALTS

1. *Nitrates.*

Sodium nitrate	$NaNO_3$	Chili saltpetre.
Potassium nitrate	KNO_3	Nitre or saltpetre.

2. *Sulphates.*

Calcium sulphate	$CaSO_4$	In hydrated form, known as gypsum or alabaster.
Magnesium sulphate	$MgSO_4 + 7\,H_2O$	Epsom salts.

3. *Chlorides.*

Sodium chloride	$NaCl$	Common salt.
Potassium chloride	KCl	

1. All the above salts may be used as plant food. What property will they then have in common?

2. By actual trial find out which has got this property in the most marked degree and which in a less degree.

3. In what respect do all the acids given above agree as regards their formulae?

SYMBOLS AND APPROXIMATE ATOMIC WEIGHTS OF SOME OF THE ELEMENTS

Aluminium	Al 27.
Calcium	Ca 40.
Carbon	C 12.
Chlorine	Cl 35·5.
Hydrogen	H 1.
Iodine	I 127.
Iron	Fe 56.
Magnesium	Mg 24.
Manganese	Mn 55.
Mercury	Hg 200·5.
Nitrogen	N 14.
Oxygen	O 16.
Phosphorus	P 31.
Potassium	K 39.
Silicon	Si 28.
Sodium	Na 23.
Sulphur	S 32.
Zinc	Zn 65.

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